STRUCTURAL CONTROLS ON MINERALISATION IN THE RENDEEP AREA, RENISON TIN MINE, TASMANIA

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the requirements for the degree of
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DECLARATION

The material presented in this thesis has not been submitted, either in whole or in part, for the award of any degree or diploma at any university or institution. This thesis does not contain any material previously published or written by another person, except where it is duly acknowledged and referenced in the text.

Signed,

Bruce McQuitty

7th Feb, 1995

ABSTRACT

Mineralisation in the Rendeep area occurs below 1700m RL (>550m from surface) at the northern end of the Renison Tin Mine, Renison Bell, western Tasmania. Probable reserves of the Rendeep area are 3.3Mt at 1.96% Sn (Thomas, 1994), compared to remaining proven and probable reserves of 6.4Mt at 1.41% Sn for the upper mine (Thomas & Roberts, 1994).

The Renison deposit is hosted by supratidal to intertidal dolomitic and siliciclastic sediments of the Renison Mine Sequence which comprises the upper ~80m of the late Precambrian Success Creek Group and the lower ~60m of the Cambrian(?) Crimson Creek Formation. Minor facies variations occur in the Rendeep area but gross thickness variations are the result of structural processes. The strongly layered Renison Mine Sequence tends to deform by interstratal slip in contrast to the rigidity of the relatively massive underlying and overlying formations.

Devonian D3 deformation, which dominates the Rendeep area, resulted from the radial stress field produced by the forceful emplacement of the Pine Hill Granite into the D2 Renison Bell Anticline axis (Kitto, 1994). The granite surface plunges northeast under the Rendeep area from its local high beneath the central part of the Renison deposit. The Federal-Bassett Fault developed over the local granite high and is transitional to a monoclinal fold in the Rendeep and North Bassett areas. Syn-intrusive, sub-vertical extension produced 770m vertical displacement of the Renison Mine Sequence in the North Bassett/Rendeep area by combined ductile and brittle processes, with ductile processes favoured by elevated temperatures and pressures(?) closer to the granite. The North Bassett Fault formed by layer-parallel extension of the Renison Mine Sequence close to its contact with overlying Crimson Creek Formation. Conjugate sub-vertical brittle-ductile extensional structures, Faults A and Z, formed subparallel to the principle stress direction. Strain transferral from the North Bassett Fault onto Faults A and Z produced a broad, concave-east open fold in the North Bassett Fault and Renison Mine Sequence north of 66400m N. The fold axial region, which plunges ~70° S, became a major upflow zone for hydrothermal fluids during later brittle reactivations. Draping of the Renison Mine Sequence along Fault Z and normal movement on the antithetic Csar Fault produced the Rendeep Graben/Syncline. Dilation of the North Bassett Fault above the Rendeep Graben/Syncline focussed hydrothermal fluid flow. Brittle dip-slip reactivation of the Federal-Bassett Fault occurred late in the D3 deformational event, faulting the crystalline carapace of the cooling Pine Hill Granite and releasing hydrothermal fluids.

D3 dextral wrench deformation accompanied the decay of the radial stress field associated with the Pine Hill Granite intrusion and a return to the regional Tabberabberan stress field (Kitto, 1994). Brittle strike-slip reactivations occurred on all major faults and

a weak dextral kink fold formed in the Renison Mine Sequence interstitial to Fault A and the North Bassett Fault, the hinge zone of which became a local focus for hydrothermal fluid flow.

Rendeep mineralisation is predominantly "stratabound", consisting of dolomite horizons of the Renison Mine Sequence replaced by an assemblage of pyrrhotite ± talc ± cassiterite and minor arsenopyrite. Stratabound mineralisation becomes more localised about feeder structures on approaching the Pine Hill Granite, due to the effect of increasing temperatures and pressures(?) on the brittle/ductile transition in dolomite. Ductile behaviour in dolomite may inhibit fluid/rock interaction by restricting fracture propagation. A radius of 400m from the Pine Hill Granite is proposed as the minimum distance to economic stratabound tin mineralisation based on sparse drilling information in the Rendeep area.

Hydrothermal fluid flow paths are identified by integrating the modelled tin grade distribution, sulphur and oxygen isotope data, and fluid inclusion data with the structural interpretation. Possible extensions to Rendeep mineralisation are predicted by extrapolating the hydrothermal fluid flow paths along controlling structural features.

STRUCTURAL CONTROLS ON THE DISTRIBUTION OF MINERALISATION IN THE RENDEEP AREA, RENISON TIN MINE, TASMANIA

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CHAPTER 1: INTRODUCTION

1.1 PREAMBLE ...

The Renison mine, Australia's largest primary tin producer, is located at Renison Bell in western Tasmania (Fig. 1.1). The mine is operated by Renison Limited which is wholly owned by Renison Goldfields Consolidated Limited.

Historical production to January, 1994, since discovery of the Renison field in 1890 is 131,500 tonnes of tin metal. Since 1960, 128,424 tonnes of tin have been produced from 14.8 million tonnes of ore at a grade of 1.22% Sn (Wilson, 1982; Thomas and Roberts, 1994). Reserves as of January, 1994 stood at 6.39 million tonnes at 1.41% in the proved and probable categories and 2.3 million tonnes at 1.18% in the mineral resource categories.

1.2 GENERAL GEOLOGY ...

The Renison deposit is an exogranitic replacement-style deposit (Patterson *et al.*,1981). It occurs above the northeast margin of the steep-sided north-northwest trending Pine Hill Granite stock that intruded syn- to post the Lower-Middle Devonian Tabberabberan orogenic event (Berry, 1992). The intrusion uplifted the overlying

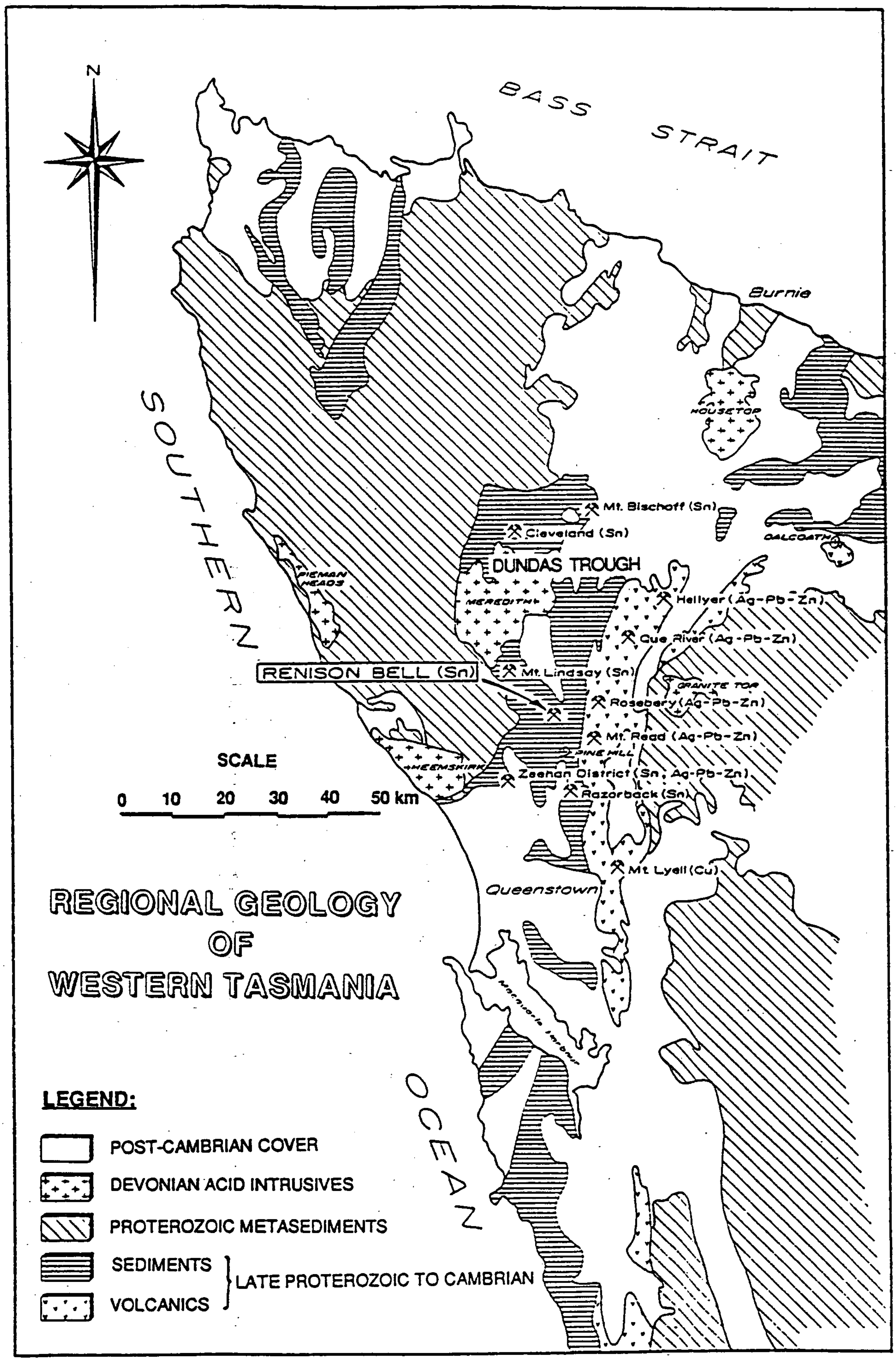
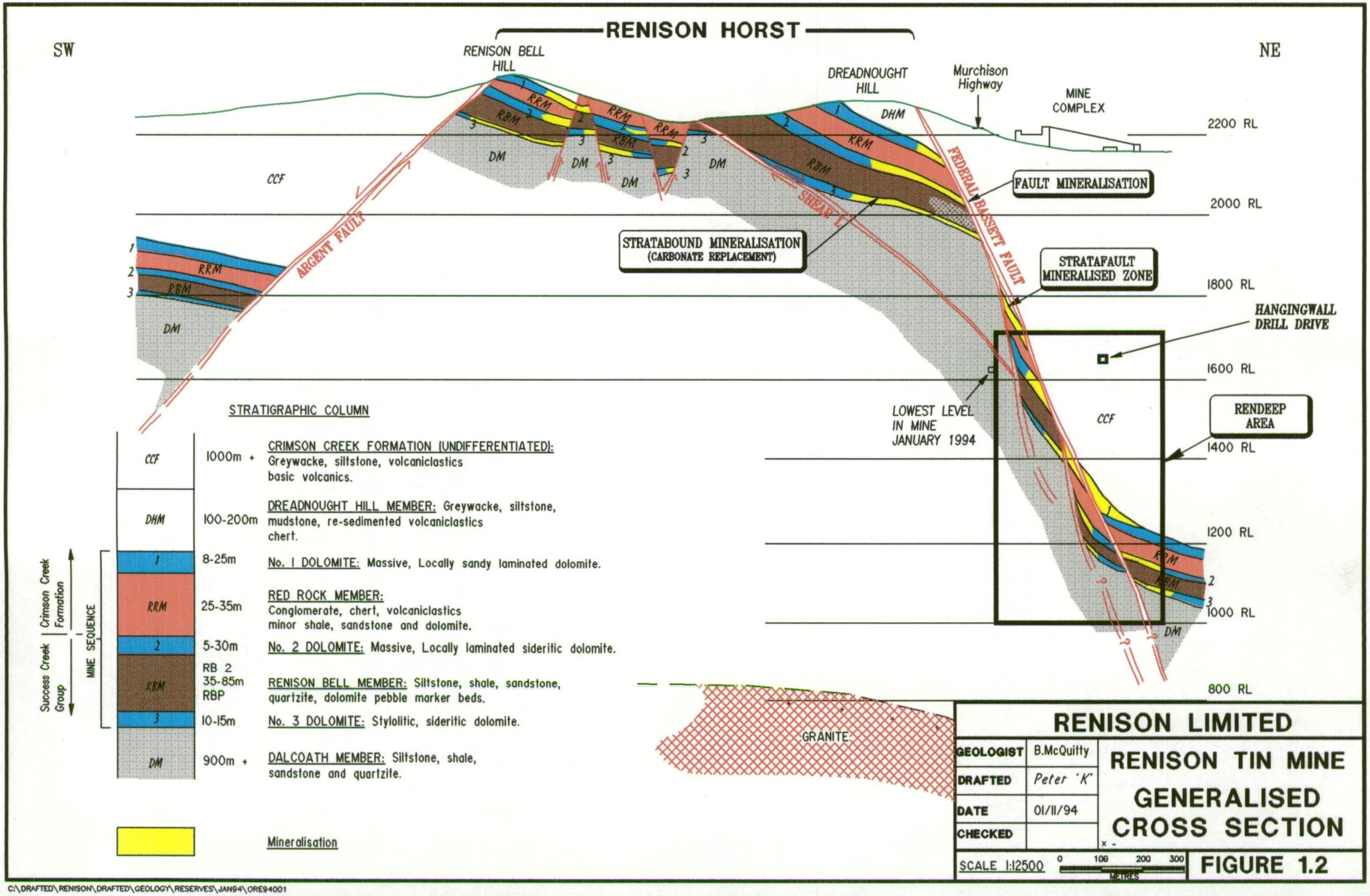


Figure 1.1 Regional geology of western Tasmania, showing the location of the Renison mine together with other major mineral deposits (after Kitto, 1994).

shallow south-easterly dipping Eo-Cambrian succession, initiating the Renison Horst through movement on the Federal-Bassett and Argent Faults (Patterson, 1979) as shown in the generalised mine cross-section (Fig. 1.2). Widespread extensional faulting created a network of permeability that provided access for hydrothermal fluids over several square kilometres outward from the Pine Hill Granite (Kitto, 1994).

The most economically significant mineralisation, comprising massive pyrrhotite (± cassiterite) occurs as replacement of carbonate horizons and is referred to as "stratabound mineralisation" (Fig. 1.2). Dolomites and dolomitic shales of the Renison Mine Sequence host the bulk of reserves (Cannard, 1991). The Renison Mine Sequence incorporates the uppermost units of the 800m+ thick Upper Proterozoic Success Creek Group and the lowermost units of the 2500m+ thick Lower Cambrian(?) Crimson Creek Formation (Morrison, 1982). Included in the Renison Mine Sequence are three principal dolomite horizons, numbered 1, 2 and 3 in reverse stratigraphic order (Fig. 1.2). The terminology for these is usually foreshortened to Number 1, 2 or 3 Horizon to encompass both the unmineralised dolomite and the replacement mineralisation.

The Federal-Bassett Fault contains significant mineralisation of the fissure infill and breccia style (Cannard, 1991). The fault intersects the granite under the mine and has been the main conduit for mineralising fluids (Holyland, 1987; Kitto, 1994). As the Renison Mine Sequence approaches the fault the bedding rotates in dip to almost parallel the fault (Fig. 1.2). Steeply-dipping blocks of Renison Mine Sequence occur between the Federal-Bassett Fault and a set of sub-parallel footwall faults, known


RENISON HORST
SW
NE
RENISON BELL HILL
DREADNOUGHT HILL
Murchison Highway
MINE COMPLEX
2200 RL
2000 RL
1800 RL
1600 RL
1400 RL
1200 RL
1000 RL
800 RL
RRM
RBM
DM
DHM
CCF
1
2
3
ARGENT FAULT
SHEAR 1
FEDERAL BASSETT FAULT
FAULT MINERALISATION
STRATABOUND MINERALISATION (CARBONATE REPLACEMENT)
STRATAFAULT MINERALISED ZONE
HANGINGWALL DRILL DRIVE
RENDEEP AREA
LOWEST LEVEL IN MINE JANUARY 1994
GRANITE
STRATIGRAPHIC COLUMN
CCF 1000m + CRIMSON CREEK FORMATION (UNDIFFERENTIATED): Greywacke, siltstone, volcaniclastics basic volcanics.
DHM 100-200m DREADNOUGHT HILL MEMBER: Greywacke, siltstone, mudstone, re-sedimented volcaniclastics chert.
1 8-25m No. 1 DOLOMITE: Massive, Locally sandy laminated dolomite.
RRM 25-35m RED ROCK MEMBER: Conglomerate, chert, volcaniclastics minor shale, sandstone and dolomite.
2 5-30m No. 2 DOLOMITE: Massive, Locally laminated sideritic dolomite.
RBM RB 2 35-85m RBP RENISON BELL MEMBER: Siltstone, shale, sandstone, quartzite, dolomite pebble marker beds.
3 10-15m No. 3 DOLOMITE: Stylolitic, sideritic dolomite.
DM 900m + DALCOATH MEMBER: Siltstone, shale, sandstone and quartzite.
Crimson Creek Formation
Success Creek Group
MINE SEQUENCE
Mineralisation
RENISON LIMITED
GEOLOGIST B.McQuitty
DRAFTED Peter 'K'
DATE 01/11/94
CHECKED
RENISON TIN MINE
GENERALISED CROSS SECTION
SCALE 1:12500
0 100 200 300
METRES
FIGURE 1.2
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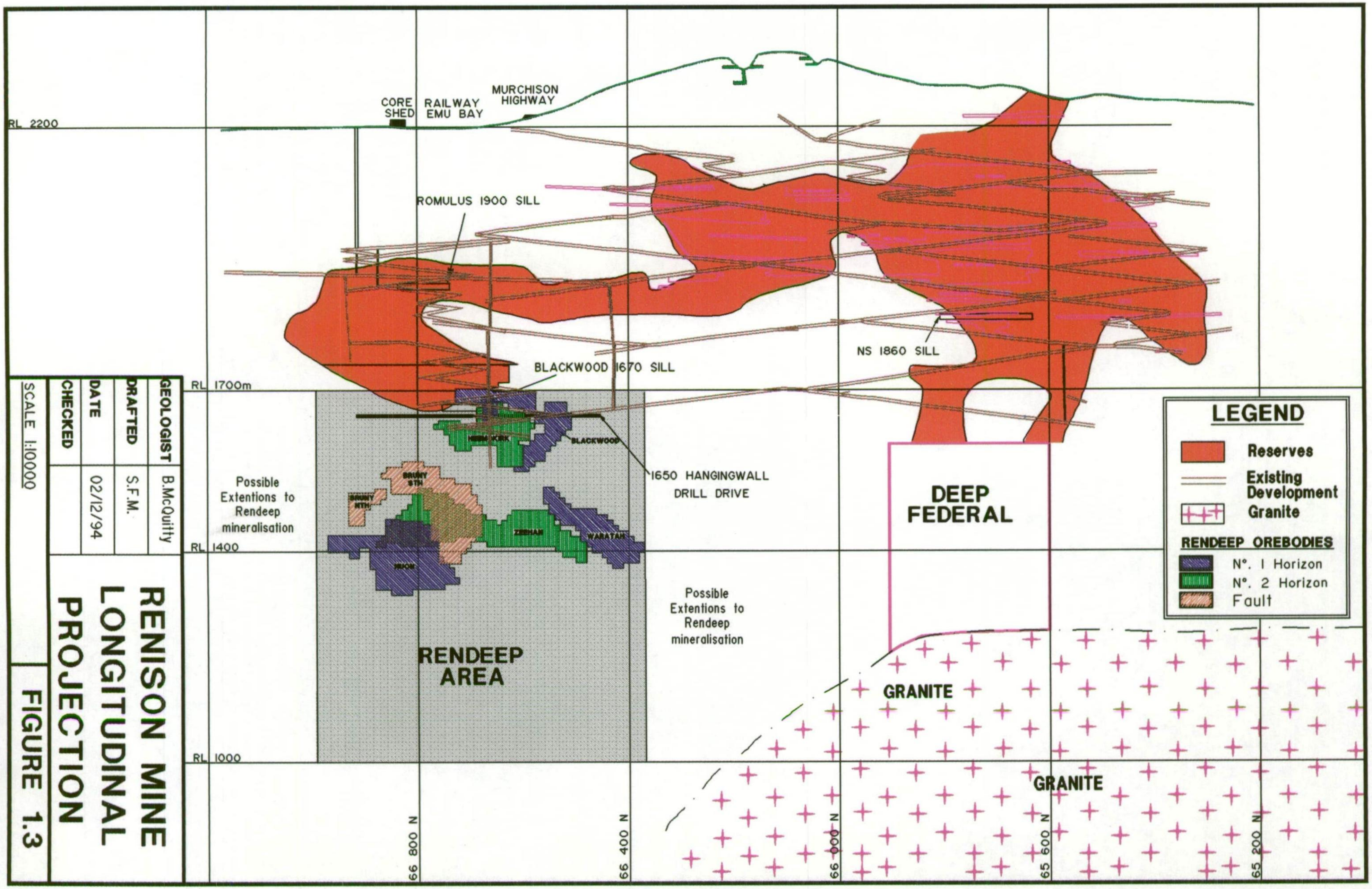
historically as "shears" (e.g., "Shear L", "Shear P") which are referred to collectively as the Transverse Faults (Patterson, 1979; Kitto, 1994). The Transverse Faults flatten in dip and rotate westward in strike as their separation from the Federal-Bassett Fault becomes greater than 30 to 50 metres (Holyland, 1987). Where the separation of the Transverse Faults and the Federal-Bassett Fault is less than approximately 30 metres, mineralisation tends to be pervasive throughout the interstitial Renison Mine Sequence rocks, including non-carbonate lithologies (Cannard, 1991). The complex combination of fault and stratabound mineralisation in this structural setting (e.g. the Envelope orebody) was historically called "stratafault" mineralisation. However, further detailed mapping and drilling by mine geologists is resolving the individual fault and stratabound mineralisation components (Thomas and Roberts, 1994).

1.3 RENDEEP AREA ...

The Rendeep area is the major focus for this study and is located below 1700m RL between 66400m N and 67000m N in the northern part of the mine (Fig. 1.2, Fig. 1.3). The Rendeep orebodies occur adjacent to and up to 200m above the point where the Mine Sequence contacts the hangingwall side of the Federal-Bassett Fault (Fig. 1.2).

In June, 1994 RGC announced a probable reserve of 3.3 million tonnes at 1.96% Sn for the Rendeep area and a further inferred resource of 3 million tonnes at 1.5% Sn for the poorly drilled north and south extensions including the deep Federal area (Fig. 1.3). In terms of contained tin, this extended Rendeep area comprises about one third of the total Renison deposit. The grade of the Rendeep reserves is 23% higher



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than that of the upper mine reserves, emphasising the area's economic importance (Thomas, 1994).

1.4 RENDEEP PROJECT ...

The Rendeep orebodies were discovered as a result of a co-ordinated exploration drilling and evaluation effort, known as the Rendeep Project, which sought to locate sufficient reserves in the deeper part of the mine to justify construction of a hoisting shaft.

Drilling commenced in January, 1990. A total of 25km of diamond drilling was carried out from surface until a review of the evaluation strategy in June, 1992 led to the construction of an underground drilling platform, known as the 1650 Hangingwall Drill Drive, in the orebody hangingwall (Fig. 1.4). Development comprised a cross-cut of 270m and an along-strike drive of 450m. This platform enabled the drilling of relatively short, accurate drillholes, improving the confidence of geological interpretation. A total of 54km of drilling had been completed on the Rendeep Project to August, 1994.

1.5 PREVIOUS WORK ...

Renison company reports by Pascoe (1982), Carrasco (1989), McQuitty (1991 and 1992), Sans (1992 and 1993a,b), Fander (1993), McQuitty et al.(1993) and Thomas (1994), record the development of understanding of the Rendeep geology, mineralisation, and grade distribution.

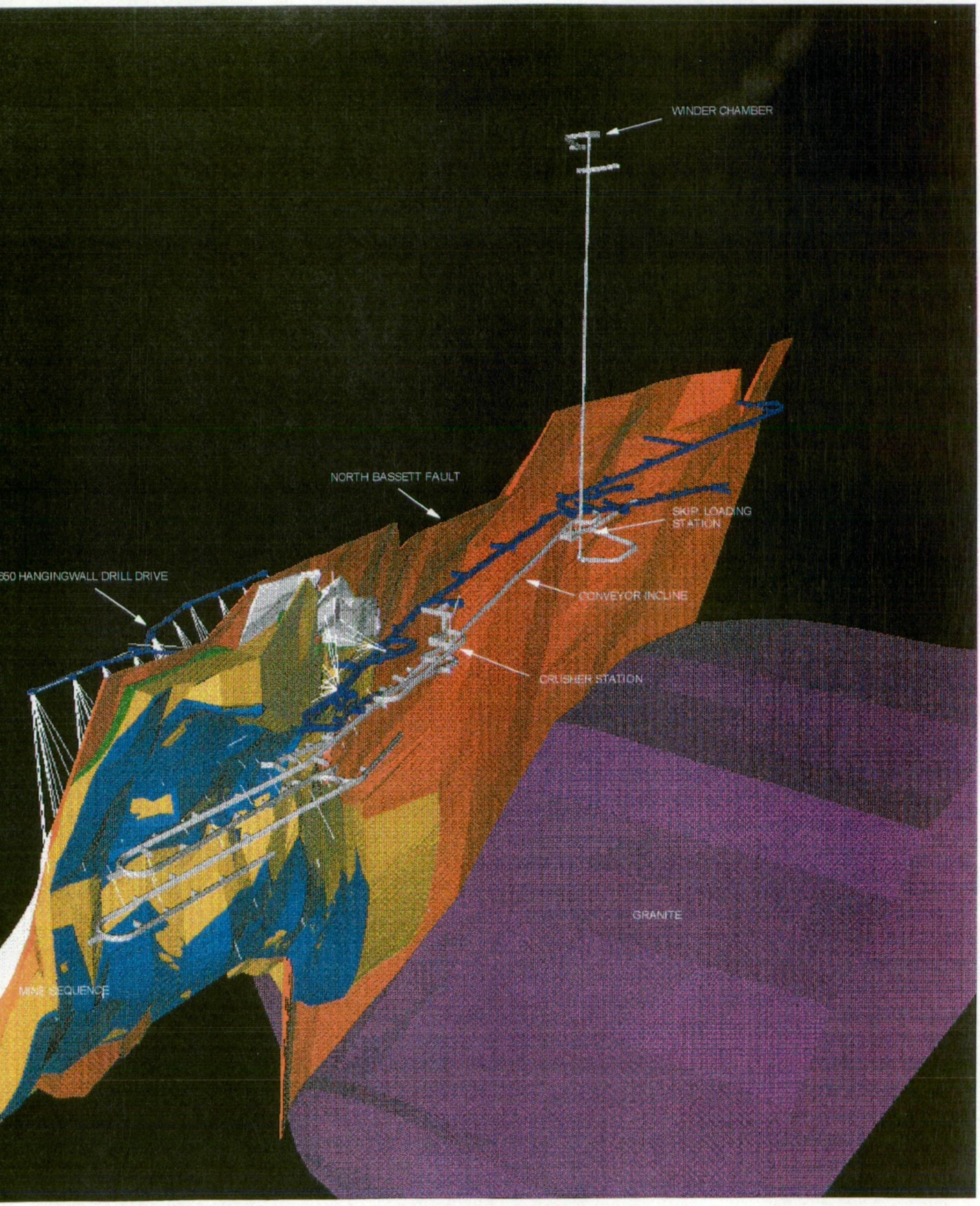


Figure 1.4 3 dimensional, Datamine-generated model of Rendeep geology, looking southeast, showing existing development (dark blue) and proposed development (grey). Fans of drillholes (white) extend from drill cuddies spaced 50m apart in the 1650 Hangingwall Drill Drive. The Federal-Bassett Fault (red) extends from 65200m N on the right, to 66975m N on the left. The Mine Sequence comprises No. 3 Horizon (blue), Renison Bell Member (yellow), No. 2 Horizon (green), Red Rock Member (orange) and No. 1 Horizon, (white). These standard colours are used in all 3 dimensional model views in this work.

Numerous workers have contributed to the overall understanding of the geology and genesis of the Renison deposit including doctoral thesies by Patterson (1979), Davies (1985), Holyland (1987) and most recently, Kitto (1994). Kitto's study has provided the most comprehensive understanding of the overall structure of the deposit, its relationship to mineral paragenesis and the pattern of hydrothermal flow. An interpretation of the morphology of the Pine Hill granite stock from gravity data by Leaman (1990) is central to Kitto's work. The spatial relationship of mineralisation to the intrusion is clearly demonstrated by the distribution of metals and stable isotopes, both in a regional sense and along the plane of the Federal-Bassett Fault. Kitto used this data, together with fluid inclusion evidence to model the pattern of hydrothermal flow, and sought to explain the observed pattern in terms of structural controls. The same methods are employed in this study.

1.6 AIMS OF THIS STUDY ...

Data gathered from the Rendeep Project is used to determine the structural evolution of the Rendeep area and the extent to which structure controlled the migratory pattern of mineralising fluids.

A structural interpretation of the Rendeep area, completed for resource estimation purposes, is used to explain the distribution of mineralisation in terms of:

1) deformation of the host rock pre- to syn-mineralisation, and

2) structural controls on migration of mineralising fluids.

Metal distribution, stable isotope and fluid inclusion studies are used to model the flow pattern of the mineralising fluids.

Implications of the study to the origins of the Renison deposit and to future exploration directions are considered.

1.7 DATABASE AND LIMITATIONS ...

Drilling associated with the Rendeep Project forms the bulk of the current database. No core orientation work was attempted due to time constraints, and the belief that a sufficient drilling density would enable a confident structural interpretation. In hindsight, core orientation would have helped to determine the orientation of the orebodies during early stages of the project.

Up to the time of writing only one underground opening existed into the uppermost levels of the Rendeep area; the 1650 Crosscut provides access to the 1650 Hangingwall Drill Drive. Stopes in the North Bassett orebodies above the Rendeep area (e.g. Blackwood 1670, Heemskirk 1670 and Romulus 1900) provide exposures of structural information that can be extrapolated to the Rendeep area. Location of underground openings referred to in this text are shown in Figure 1.3; all other textural and structural observations have been taken from drill core.

CHAPTER 2: STRATIGRAPHY AND SEDIMENTOLOGY

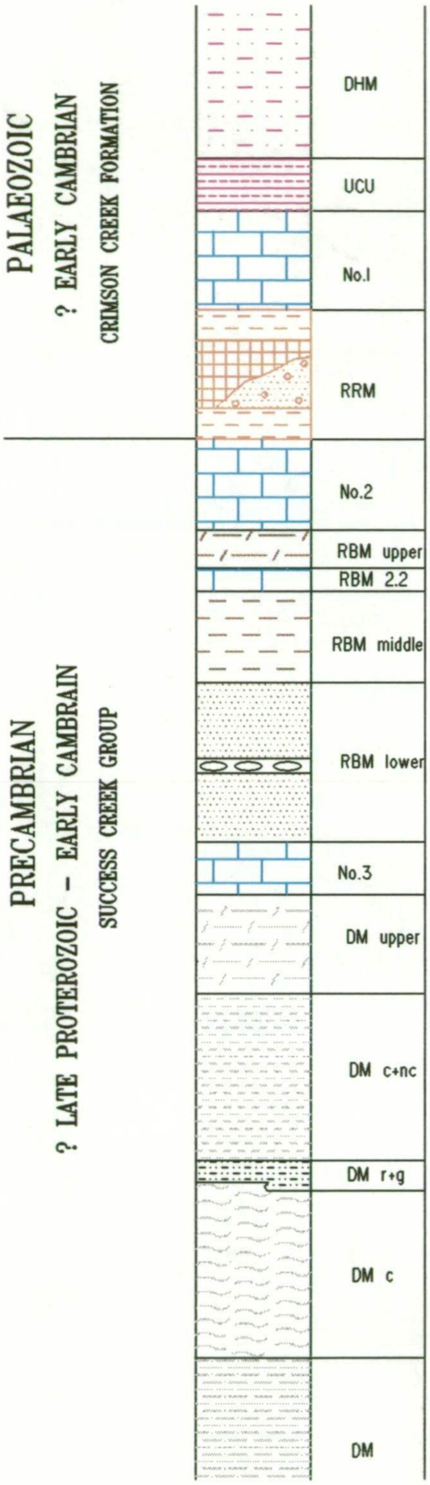
2.1 INTRODUCTION ...

An understanding of Renison's stratigraphy and sedimentology is essential for an accurate structural interpretation. Primary variation in the thickness of strata (which in the case of the dolomite horizons limits the extent of potential replacement mineralisation) need to be considered in terms of sedimentological processes before structural deformation is considered. Primary sedimentological features can also strongly influence the rheology of particular stratigraphic units.

The Renison Mine Sequence straddles the boundary of the Proterozoic Success Creek Group and the Cambrian Crimson Creek Formation, and is considered here as a separate subdivision for structural and economic purposes (Fig. 2.1).

2.2 DALCOATH MEMBER ...

The Dalcoath Member is the basal unit of the Success Creek Group in the mine area. It is at least 900m thick and unconformably overlies Precambrian Oonah Formation (Brown, 1986). Morrison (1982) subdivided the upper 150 metres of the Dalcoath Member below the No.3 Horizon. Due to a perceived lack of economic potential,



DREADNOUGHT HILL MEMBER: Green and red - brown siltstone and greywack, minor basalt, tuff

UPPER CONTORTED UNIT (0-45m): Red siltstone, chert, lapilli tuff, locally contorted black shale, siltstone, sandstone

No.I DOLIMITE (8-25m): Grey stylolitic, laminated dolimite, impure margins, locally sandy

RED ROCK MEMBER (25-35m): Interbedded red, white and grey sanstone, conglomerate, siltstone, chert, jasper and iron formation, local volcanic fragments

NO.2 DOLIMITE(5-30m): Grey stylolitic dolomite locally laminated, pelletal or with red-lined cavities

RENISON BELL MEMBER upper(5-10m): Grey-green dolomite siltstone

RENISON BELL MEMBER 2.2 (I-3m): Nodular dolomite, siltstone.

RENISON BELL MEMBER middle (10-30m): Black shale, minor sandstone, siltstone, conglomerate

RENISON BELL MEMBER lower (10-30m): Quartz sandstone, shale partings, pebble beds to 10m, local basal intraclast conglomerate.

No.3 DOLOMITE (to 15m): Grey stylolitic dolomite, locally laminated, pelletal; locally divided in two by shale.

DALCOATH MEMBER upper(10-15m): Grey-green dolomitic siltstone and shale with nodular dolomite, tuff beds.

DALCOATH MEMBER carbonaceous and non-carbonaceous unit (8-54m): Grey and black laminated siltstone, locally colour mottled slump folded, broken. Minor sandstone, shale beds.

DALCOATH MEMBER red and green unit (to 54m): Siltstone, sandstone, shale.

DALCOATH MEMBER contorted unit (to 80m): Black to grey shale and siltstone with broken beds of sandstone.

DALCOATH MEMBER undivided (to 800m): Massive quartz sandstones, shale and siltstone in upper part

GEOLOGIST	B.MQuitty	STRATIGRAPHY OF THE RENISON MINE SEQUENCE
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DATE	17/11/94	AFTER MORRISON,1982
CHECKED		
SCALE 1:1000		FIGURE 2.1

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relatively few drillholes have tested further than 50 metres below the No. 3 Horizon, locating minor, thin dolomite horizons (Lea, 1991). Approximately 800 metres of the Dalcoath Member has not been subdivided (Morrison, 1982). The majority of the Dalcoath Member is massive quartz sandstone with lesser carbonaceous shale and siltstone (Morrison, *op. cit.*).

2.2.1 Dalcoath Contorted Unit ...

The Dalcoath contorted unit occurs up to 150 metres below the Renison Mine Sequence. Morrison (1982) described it as a distinctive zone of irregular thickness (up to 80m) consisting of broken angular fragments of bedded sandstone, floating in a matrix of contorted laminated black shale.

2.2.2 Other Dalcoath Member Units ...

The distinctive Dalcoath Red and Green siltstone unit noted by Morrison (1982; Fig.2.1) as overlying the Dalcoath between the Argent Dam and the mine portal (Fig. 2.2) is not observed in the Rendeep area.

The Dalcoath Carbonaceous and Non-Carbonaceous siltstone unit (8-54m; Fig. 2.1) consists of undisturbed, mottled-grey to black laminated siltstone and shale with wavy, cross-bedded and locally slump-folded siltstone and minor sandstone laminae. The upper portion is well laminated, resembling the middle part of the Renison Bell Member (Morrison, 1982).

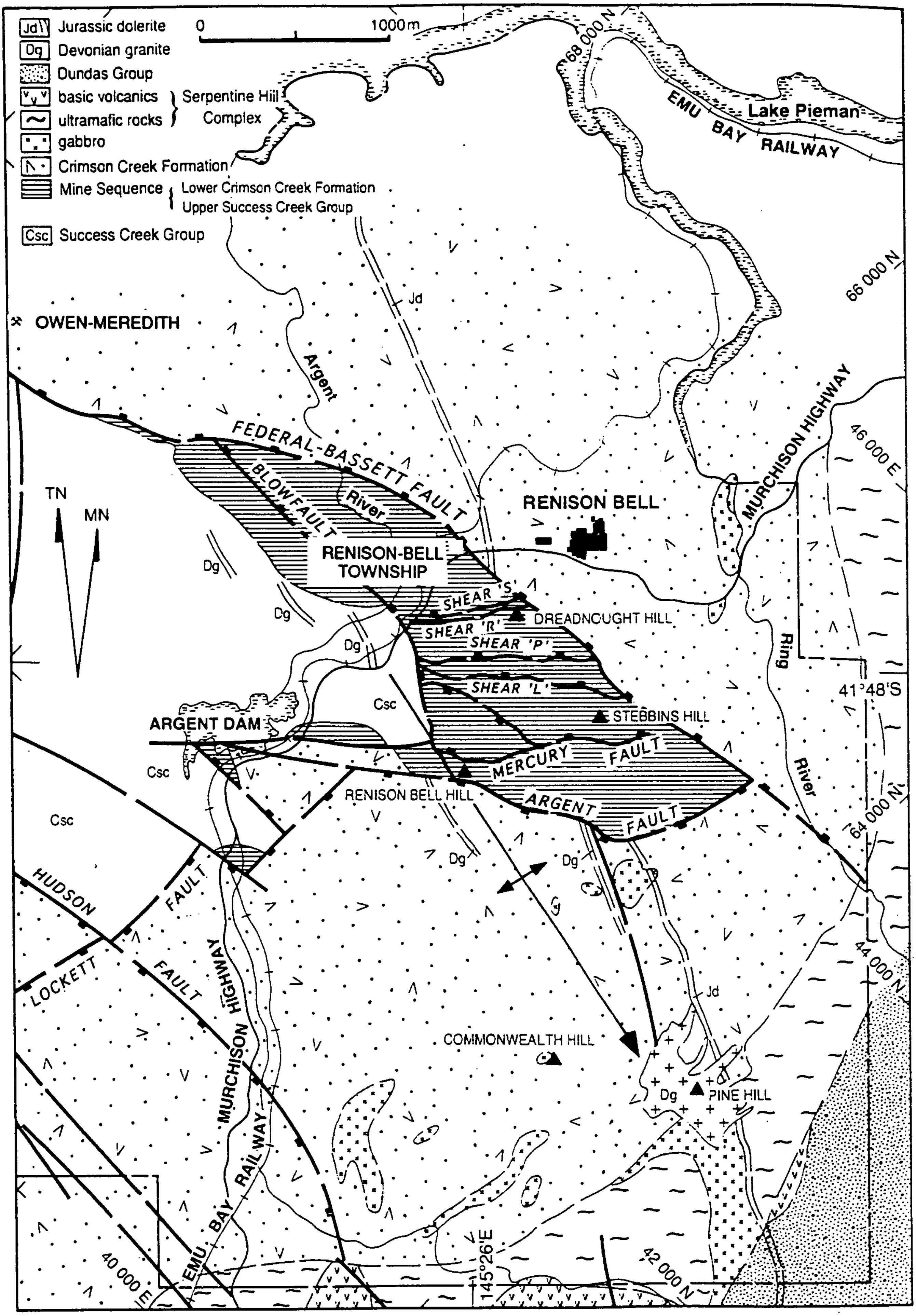


Figure 2.2 Geological interpretation of the Renison district, compiled from mapping by Renison Ltd geologists and from detailed 1: 2000 cross-sectional interpretations (Kitto, 1994).

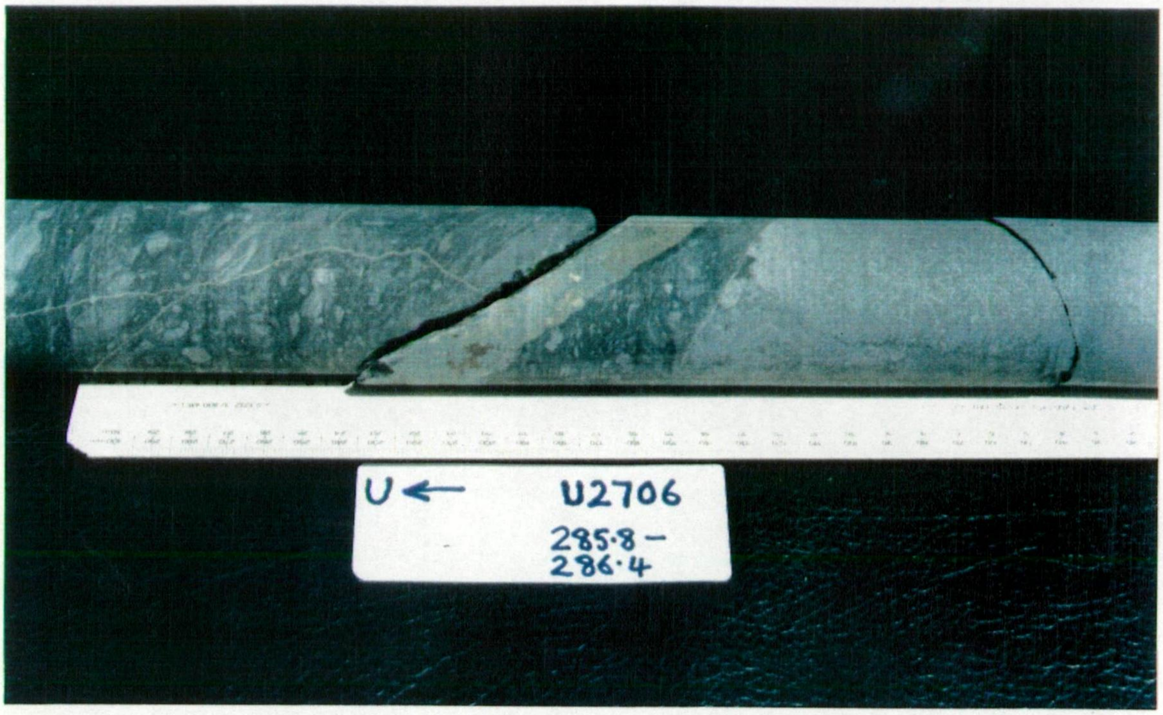


Plate 2.1 Contact of massive sandstone bed (right) with contorted shale containing sandstone fragments (left), Dalcoath Contorted unit, curved core surface, U2706, 285.8-286.4m

Plate 2.2 Dalcoath Contorted unit, showing flattening and alignment of sandstone clasts parallel to foliation, curved core surface, U2706, 313.8m

The Dalcoath Upper unit consists of shale and siltstone with interbeds of nodular dolomite. The unit resembles the upper Renison Bell Member (Morrison, 1982; Fig. 2.1). In the Rendeep area the siltstone beds have a distinctive red-brown and green colour and the dolomite beds are often silicified. The unit is useful as a marker horizon to distinguish the Dalcoath Member from the Renison Bell Member in the absence of the No. 3 Horizon.

2.2.3 Significance to the Structural Interpretation ...

Morrison (1982) interpreted the contorted and broken textures of the Dalcoath contorted unit as slumping of partly consolidated sediment in an intertidal environment cut by tidal channels. This conclusion is supported by evidence from the Rendeep area in drillhole U2706 (Appendix 1, Section 66550m N) where a massive undisturbed sandstone bed was intersected adjacent to highly deformed shale containing sandstone fragments (Plate 2.1.). This unit frequently displays an overprinting tectonic foliation (Brown, 1986). An example of this tectonic foliation from the Rendeep area is shown in Plate 2.2. The unit is weaker than the surrounding massive lithologies and deforms more readily.

2.3 RENISON MINE SEQUENCE ...

The Renison Mine Sequence has been well documented by Morrison (1982) and is summarised in Figure 2.1. Individual members are described below.

2.3.1 No. 3 Horizon ...

The No. 3 Horizon is a massive grey dolomite up to 15 metres thick, which is discontinuous in the southern part of the mine (Morrison, 1982; Fig 2.1) and in parts of the Rendeep area. Morrison (*op. cit.*) noted that the No. 3 Horizon is split in two by a shale and siltstone sequence in the Owen Meredith-Dunkley Tram-Argent Dam area (Fig. 2.2). A similar facies variation is observed in the northern part of the Rendeep area (Section 2.6).

2.3.2 Renison Bell Member ...

The Renison Bell Member (30-80m) consists of three sub-units which can be broadly correlated but which have lenticular distributions on a local scale (Morrison, 1982; Fig. 2.1):

i) a lower unit comprising 20 to 40 metres of massive fine-grained quartz sandstone with distinct pebble conglomerate beds to 10 metres thick,

ii) a middle unit (10-30m) of laminated carbonaceous shale, siltstone and sandstone, and

iii) an upper unit (5-10m) of interbedded dolomitic siltstones and shales overlying a discrete dolomite bed (1-3m) known as the 2.2 Horizon.

2.3.3 No. 2 Horizon ...

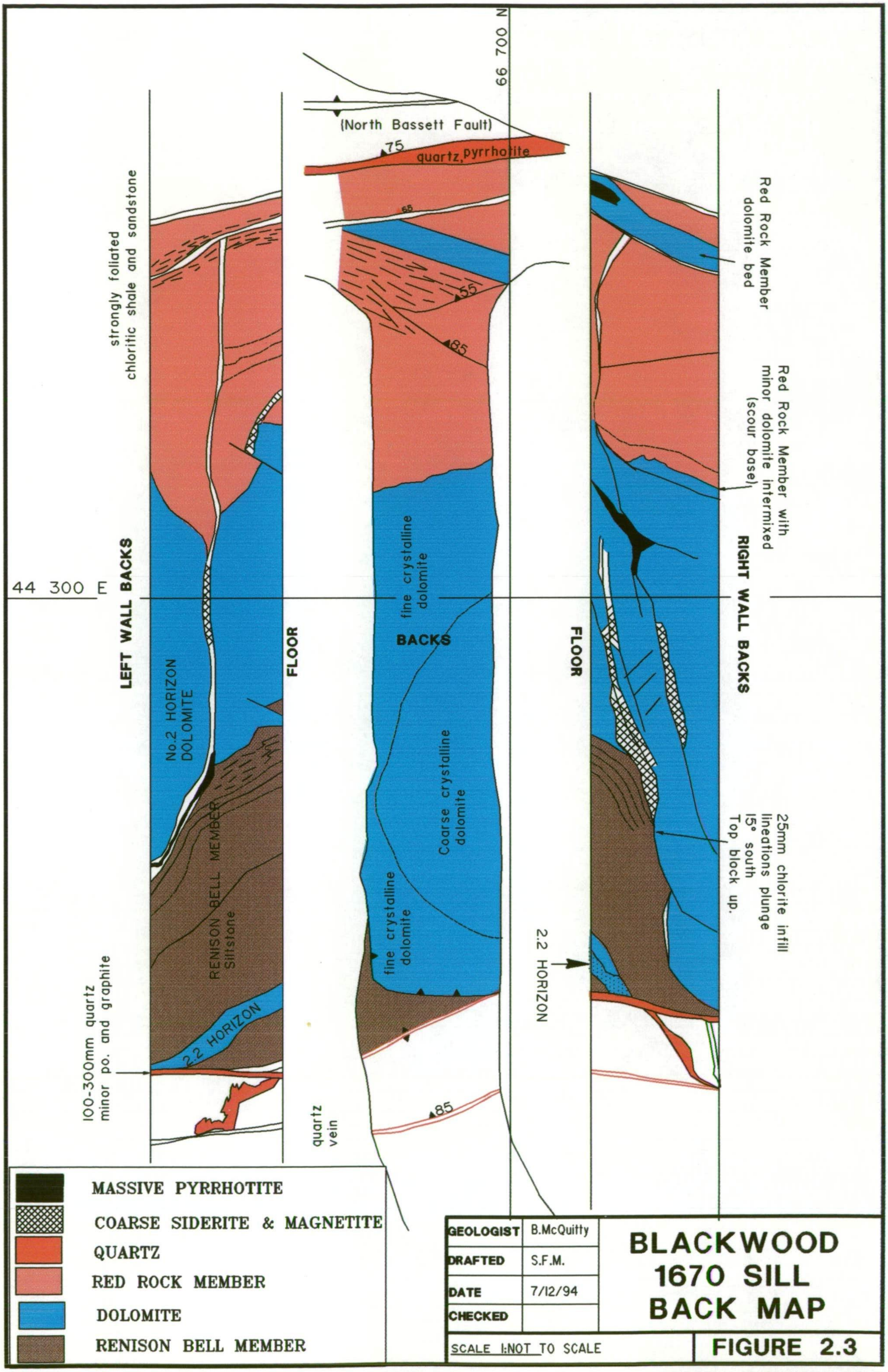
The No. 2 Horizon dolomite (5-30m) is texturally and compositionally similar to the No. 3 Horizon except for a characteristic impure gradational lower margin and minor silty interbeds. It is the most laterally continuous of the three main dolomite horizons (Morrison, 1982; Fig. 2.1).

2.3.4 Red Rock Member ...

The Red Rock Member (25-35m) is a distinctive horizon which defines the base of the Crimson Creek Formation and marks the first substantial appearance of mafic volcanic detritus in the Dundas Trough (Brown, 1986). Morrison (1982) subdivided the Red Rock Member into 3 subunits:

i) a basal unit of intraclastic conglomerate and tuffaceous rocks occur in channels scoured in No. 2 Horizon dolomite and interpreted by Morrison (1982) as lag deposits. This interpretation is reinforced by mapping carried out for this study in the Blackwood 1670 Sill access, where clasts of No. 2 Horizon dolomite are incorporated into the basal Red Rock Member unit above an uneven contact interpreted as a scour base (Fig. 2.3),

ii) a middle unit of graded conglomerate, siltstone and dolomite sequences, interpreted as channel fill and point bar deposits (Morrison, 1982; Fig. 2.1) and


66 700 N
(North Bassett Fault)
75
quartz, pyrrhotite
65
55
85
strongly foliated chloritic shale and sandstone
Red Rock Member dolomite bed
Red Rock Member with minor dolomite intermixed (scour base)
44 300 E
LEFT WALL BACKS
FLOOR
BACKS
FLOOR
RIGHT WALL BACKS
fine crystalline dolomite
Coarse crystalline dolomite
fine crystalline dolomite
No.2 HORIZON DOLOMITE
RENISON BELL MEMBER Siltstone
2.2 HORIZON
2.2 HORIZON
25mm chlorite infill lineations plunge 15° south Top block up.
100-300mm quartz minor po. and graphite
quartz vein
85
MASSIVE PYRRHOTITE
COARSE SIDERITE & MAGNETITE
QUARTZ
RED ROCK MEMBER
DOLOMITE
RENISON BELL MEMBER
GEOLOGIST B.McQuitty
DRAFTED S.F.M.
DATE 7/12/94
CHECKED
SCALE I:NOT TO SCALE
BLACKWOOD 1670 SILL BACK MAP
FIGURE 2.3
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iii) an upper unit of chert, iron formation, laminated siltstone and dolomite interpreted as cut-off lake deposits (Morrison, 1982 ; Fig. 2.1).

Although this sequence is commonly recognised, the subunits have a lenticular distribution, their order is sometimes interchangeable and the proportion of individual rock types varies (Morrison, 1982). This is consistent with a fluvial origin.

2.3.5 No. 1 Horizon ...

The No.1 Horizon dolomite (5-25m) is similar to the No. 2 and No. 3 Horizon dolomites apart from a higher clastic content (Morrison, 1982; Fig. 2.1). It has an apparently conformable relationship with cherts and siltstones of both the overlying and underlying sequences.

2.3.6 Significance to the Structural Interpretation ...

The three main dolomite horizons of the Renison Mine Sequence are thought by Morrison (1982) to have formed in a supratidal to intratidal algal flat environment, with the Renison Bell Member and the Dalcoath carbonaceous and non-carbonaceous unit interpreted to occur in a mudflat to sandflat environment. Morrison noted the lenticular nature of individual members in the mine area and a gradual thinning of the dolomite horizons to the south, interpreted as a gradual facies change. However, at least some of the thinning could be interpreted as being due to strain shortening approaching the apex of the granite at Pine Hill. Both facies change and structural thinning are suggested as processes to explain a similar thinning of the Crimson Creek Formation towards Pine Hill (Morrison, 1993).

Generally, the intratidal to supratidal facies are laterally continuous enough for confident correlation over several hundred metres, except for where incision by, or intercalation of fluvial facies occurs. Fluvial facies are represented by the Red Rock Member, and to a lesser extent by the pebble conglomerate beds of the Renison Bell Member. The Red Rock Member, itself, is a relatively thick unit with high lateral continuity (Morrison, 1982). Erosion of the No.2 Horizon prior to deposition of Red Rock Member may account for some thickness variation of the No. 2 Horizon that cannot be explained purely by structural processes (Chapter 3, Section 3.5.5). The interfingering of Red Rock Member lithologies with the No.1 Horizon dolomite is frequently encountered in the Rendeep area (Appendix 1, sections 66800m N to 66975m N) creating complexities for structural interpretation.

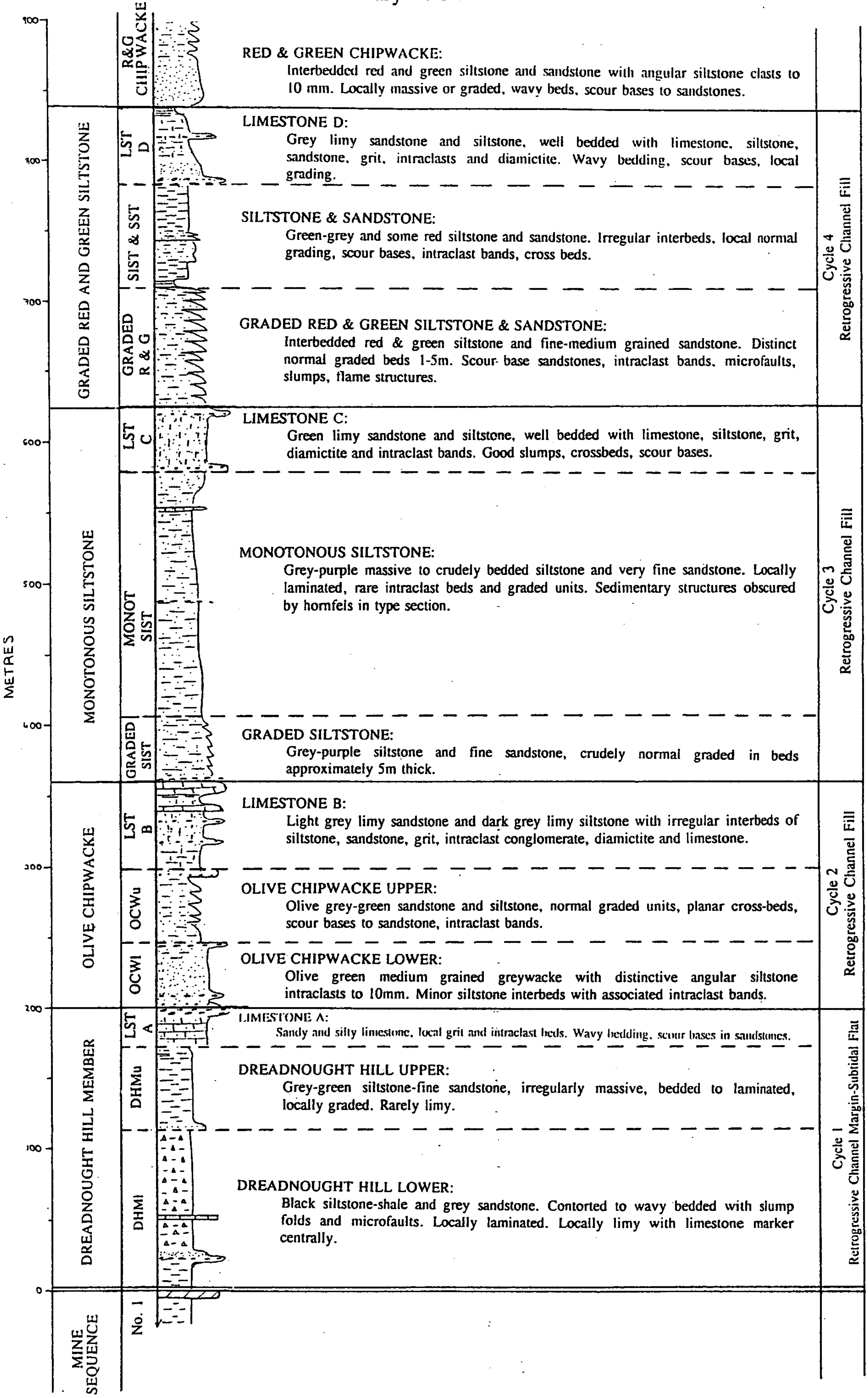
2.4 LOWER CRIMSON CREEK FORMATION ...

Haines (1991) provided the first study of the lower 900 metres of the Crimson Creek Formation in the mine area. He produced stratigraphic logs of 4 Rendeep surface drillholes and attempted to correlate the lithofacies. He concluded that the Crimson Creek Formation consisted primarily of reworked tholeiitic volcaniclastic detritus with variable amounts of calcium carbonate.

Morrison (1993) studied 12 drillholes widely located around the Mine Lease and

FIG. 2.4 STRATIGRAPHY OF THE CRIMSON CREEK FORMATION

Preliminary version G. Morrison 1/93



developed a preliminary stratigraphy for the lower 900 metres of the Crimson Creek Formation by recognition of sedimentary cycles with distinct sequences of lithologies rather than by attempting to correlate individual lithologies. The generalised interpretation is presented in Figure 2.4. Individual members are discussed below.

2.4.1 Dreadnought Hill Member ...

Morrison (1993) subdivided the Dreadnought Hill Member into three subunits. The Dreadnought Hill Lower subunit (about 120m) is a dark grey siltstone and sandstone with contorted to wavy bedding. Up to 15 metres of pink to grey banded chert and siltstone occurs sporadically at the base of the unit, conformably overlying the No.1 Horizon in parts of the Rendeep area (Section 2.6 and Chapter 3, Section 3.5.7). Morrison (*op. cit.*) also noted a limestone marker bed located centrally within the subunit. The Dreadnought Hill Upper subunit (80 to 120m) consists of monotonous siltstone to fine sandstone, rarely limey, with some graded locally laminated bedding. The capping subunit, Limestone A, is an interbedded sandy and silty limestone, typically with an intraclast bed, diamictite or black shale at its upper contact (Morrison, 1993).

2.4.2 Olive Chipwacke Unit ...

The Olive Chipwacke Unit (about 100m) is a massive or graded sandstone-siltstone with an olive green colour due to abundance of volcanic detritus. Grit to cobble size angular clasts of siltstone, clearly derived from disaggregated siltstone beds within the formation, are disseminated throughout the sand or silt matrix. The unit has been subdivided by Morrison (1993) into a massive lower subunit and a graded, coarsely bedded upper unit.

2.4.3 Limestone B ...

Limestone B (20 to 50m) overlies the Olive Chipwacke Unit. It is more impure and has more clastic interbeds than Limestone A (Morrison, 1993). Irregular sized interbeds of siltstone, sandstone, grit, intraclast conglomerate and diamictite occur with the limestone.

2.4.4 Monotonous Siltstone Unit ...

The monotonous grey-purple siltstone-sandstone unit (to 200m) is usually massive, with few sedimentary features other than rare coarse graded, laminated and intraclast beds (Morrison, 1993).

2.4.5 Significance to the Structural Interpretation ...

The depositional environment for the Lower Crimson Creek Formation is interpreted by Morrison (1993) to occur in shallow water subtidal to intertidal areas with turbidite channels draining a mud flat. He recognised a cyclic pattern of lithologies (massive sandstone to interbedded sandstone and siltstone grading to massive siltstone, capped by clastic carbonate), interpreted as a shallowing upward cycle. The massive to coarse, turbiditic bedding and the 100 metre plus thickness of most subunits indicates a rapid rate of sedimentation into a developing basin in which sedimentation kept pace with subsidence. For this reason the possibility of syn-sedimentary faulting within the Dundas Trough should be considered during structural interpretation.

The definition of individual units of the Crimson Creek Formation is difficult because of the homogeneity of composition and grainsize and the gradational nature of most lithological contacts. Calcareous diamictite horizons occurring in association with silty limestones form the most useful stratigraphic markers in the Rendeep area. The Crimson Creek Formation stratigraphy can be used to predict depth to the underlying Renison Mine Sequence. The stratigraphy of the lower 300 metres has been used in this study to resolve the structure in the region overlying the Rendeep orebodies (Chapter 3, Section 3.5.3).

2.5 FACIES VARIATIONS IN THE RENDEEP AREA ...

In the Rendeep area there are some noteable variations to the generalised Renison Mine Sequence and Crimson Creek Formation.

i) The No.3 Horizon is generally less than 5 metres thick and is frequently absent. Much of the observed thinning may be due to structural processes as discussed in Chapter 3. The thickness of the No. 3 Horizon increases to the north of the Rendeep area. Drillhole S1464A intersected a split No. 3 Horizon,

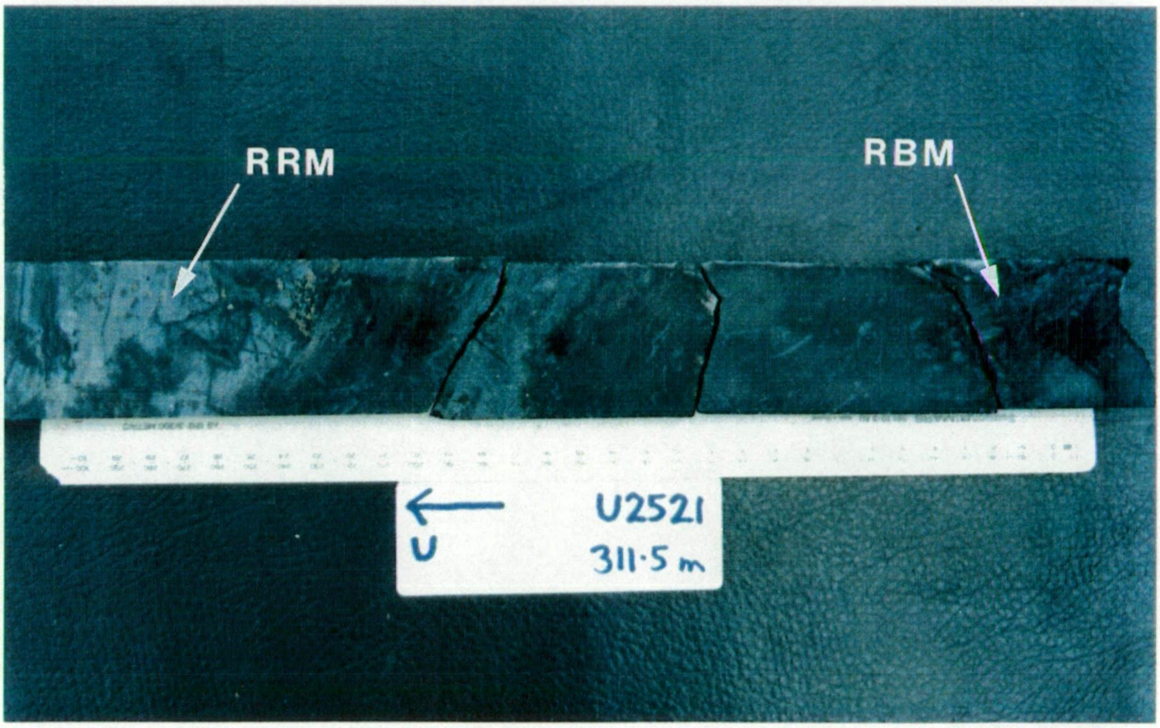


Plate 2.3 Contact between Renison Bell Member (RBM) siltstone and overlying Red Rock Member (RRM) chert in drillhole U2521, 311.5m. The No. 2 Horizon, upper Renison Bell Member and 2.2 Horizon are missing from the stratigraphy. The contact is interpreted as an erosional disconformity.

separated by a thick Renison Bell pebble conglomerate unit (Appendix 1, section 67000m N).

ii) North of 66750m N, there is a marked thinning of the No.2 Horizon below 1350m RL. In drillhole U2521 (Plate 2.3), the Red Rock Member disconformably overlies the Renison Bell Member.

iii) The No.1 Horizon thickens northward and multiple intercalations occur with Red Rock Member lithologies (see Appendix 1, section 66950m N).

iv) A semi-continuous nodular to banded pink to grey chert unit, similar to the lower Red Rock Member, occurs above the No.1 Horizon. This unit was also noted by Morrison (1982) around Renison Bell Hill (Fig. 2.2) and is useful for determining conformability of the overlying Dreadnought Hill Member contorted siltstone with the No.1 Horizon.

v) Limestone B of the Crimson Creek Formation is poorly defined or absent from most of the Rendeep area due to lateral facies variation.

2.6 RHEOLOGICAL SIGNIFICANCE ...

Sedimentological properties such as bedding, grainsize, porosity, composition, as well as diagenetic and metamorphic processes can influence the rheology of a sedimentary rock. The rock descriptions given above together with rock strength test results and RQD measurements on Rendeep drillcore reported by Fudge (1993) and McQuitty (1994) provide some semi-quantitative data to comment on the respective rheology of each of the major stratigraphic units. (RQD = Rock Quality Designator (%) = [sum of lengths of core >10cm / total length of core] x 100/1, for a given interval, in this case the distance between core blocks).

Fudge (1993) carried out a statistical analysis of RQD measurements for each of the major rock units in the Rendeep area. The results are shown in a series of histograms in Figure 2.5. A low RQD number reflects a high proportion of discontinuities, namely joints, faults and bedding plane partings, in the rock mass .

The Dalcoath Member has a high average RQD (78%), which reflects the generally massive or poorly defined bedding and only a moderate amount of jointing. Slightly lower mean RQD values were recorded for the Crimson Creek Formation (71%), Dreadnought Hill Member (70%), and No. 1 Horizon (75%) which again reflects the generally massive character of these units. The bimodal distribution of RQD values in the No. 1 Horizon is due to the proximity of the Federal-Bassett Fault. The Renison Bell Member and Red Rock Member have significantly lower mean RQD values of 57% and 60% respectively and display a normal frequency distribution as opposed to the strongly positively skewed distributions of the Dalcoath Member and Crimson Creek Formation. Bedding plane partings along carbonaceous shale laminae, particularly in the middle subunit, contribute to the low RQD values of the Renison Bell Member. Strong joint development in the brittle chert beds and well developed bedding, relative to the Dalcoath and Crimson Creek Formation, account for the low

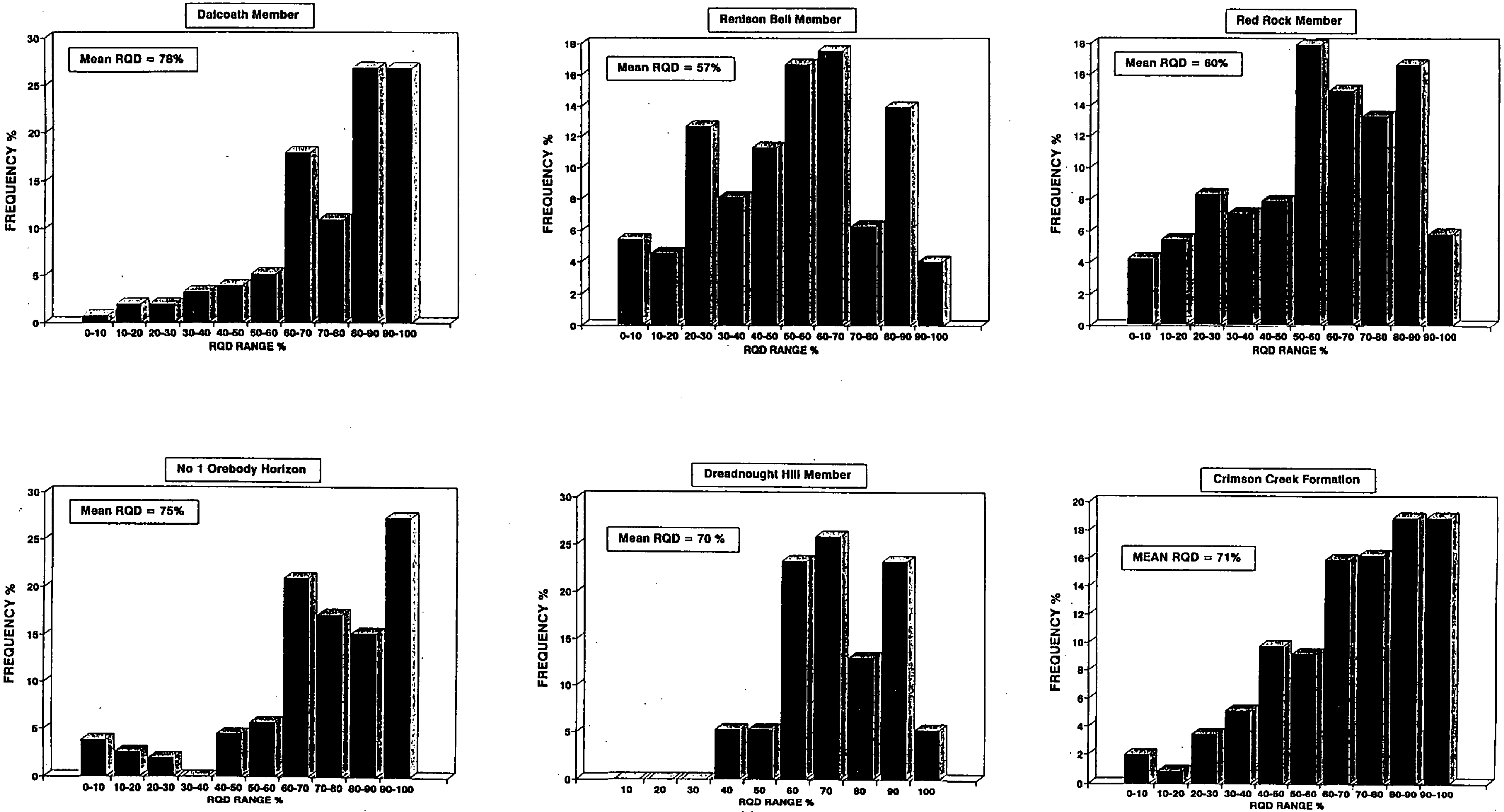


Figure 2.5 Frequency distribution of RQD data for six major stratigraphic subdivisions, measured from Rendeep drillcore (after Fudge, 1993).

RQD values in the Red Rock Member.

Results of strength testing, carried out at Renison using a hydraulic point loader (Fudge, 1993) and separate uniaxial compressive strength tests undertaken at the University of Melbourne's Engineering faculty (McQuitty, 1994), indicate all rock formations are very strong to extremely strong (100-270 MPa) except where weakened by hydrothermal alteration or replaced by weaker mineral assemblages such as talc and chlorite. Hornfelsed rocks of the Dalcoath Member, Red Rock Member cherts and metasomatised Crimson Creek Formation rocks gave the strongest values.

These results are consistent with the observations of Holyland (1987) that the Dalcoath Member acted as a rigid forcing member during deformation, while the more laminated members of the Mine Sequence were prone to loss of cohesive strength due to higher frequency of bedding plane partings. The overlying Crimson Creek Formation would also tend to be more rigid than the underlying Mine Sequence due to the absence of well defined bedding planes. Deformation of a relatively weak, stratified Mine Sequence between two relatively strong, rigid formations would be facilitated by interstratal slip rather than faulting, resulting in a style of deformation similar to the drape folding proposed by Holyland (1987).

2.7 SUMMARY ...

The sedimentary rocks of the upper 150m of the Dalcoath Member and the Renison

Mine Sequence are interpreted as forming in a supratidal to intertidal environment whereas the Crimson Creek Formation was deposited in a shallow subtidal to intertidal environment (Morrison, 1982 & 1993). Despite the lenticular distribution of subunits, lateral continuity of major units is high, enabling confident correlation between drillholes over several hundred metres. Minor facies variations in the Rendeep area include local discontinuities in the No. 2 and No. 3 Horizons. The Red Rock Member, the most significant fluvial facies, interfingers with the No. 1 Horizon dolomite and incises the No. 2 Horizon dolomite, producing local thickness variations in these units.

A preliminary stratigraphy for the lower 900m of the Crimson Creek Formation, developed by Morrison (1993), provides additional means of interpreting the structure of the Rendeep area.

Through assessment of the rheological properties of the Renison Mine Sequence rocks the strongly layered Renison Mine Sequence is predicted to deform by interstratal slip as opposed to the rigid behaviour predicted for the more massive, underlying Dalcoath Member and overlying Crimson Creek Formation.

The stratigraphic, sedimentological and rheological information presented in this chapter is used for the structural interpretation of the Rendeep area, presented in Chapter 3.

CHAPTER 3: STRUCTURE

3.1 INTRODUCTION ...

A review of the major stratigraphic units and their rheological properties in Chapter 2 provides the basis for a presentation of a structural interpretation of the Rendeep area. Previous work is reviewed in order to present an overview of the structural history of the region. The structural interpretation for the Rendeep area is then presented. This chapter highlights the processes by which dilatant sites were generated for the focussing of mineralising fluids, a relationship that is explored further in Chapter 4.

3.2 PREVIOUS WORK ...

Previous structural investigations on the Renison mine lease include studies by Patterson (1979), Patterson et al. (1981), Davies (1985), Holyland (1987), Marjoribanks (1989 & 1990), Kitto (1990), and Lea (1991). Kitto (1992 & 1994), and Kitto and Berry (1991 & 1992) were the first to use kinematic indicators on fault surfaces to derive stress tensors and hence resolve the brittle deformational history within the mine.

3.2.1 Pre-Tabberabberan Deformation ...

Deformation events in the Dundas Trough during the Cambrian and Ordovician have been proposed by Corbett and Lees (1986). Holyland (1987) noted recumbent intrafolial rheomorphic folds in the Dalcoath Member, and in the Renison Bell Member which were spatially related to the Federal-Bassett Fault and "Shears L and P" which are considered Devonian Tabberabberan structures (Kitto, 1994). Holyland (1987) thought these folds may relate to post depositional deformation during Early Cambro-Ordovician or Devonian Tabberabberan events.

Folded and contorted bedding in the Dalcoath Contorted and Dreadnought Hill Lower units was interpreted by Morrison (1982) as syn-depositional slump folds forming in tidal channels draining a mud flat (Chapter 2, Section 2.2.1).

Davies (1985) and Holyland (1987) considered that there was no evidence for syn-sedimentary growth faults at Renison, however, Morrison's (1993) interpretation of a cyclic shallow water to intertidal depositional environment for the lower 900 metres of the Crimson Creek Formation implies that syn-sedimentary growth faults must have developed somewhere within the Dundas Trough (Section 2.4.5), therefore the possibility of their occurrence at Renison should not be dismissed.

3.2.2 Devonian D1 Deformation ...

Brown, (1986) and Holyland (1987) have defined a weak asymmetric open folding of the Success Creek Group and Crimson Creek Formation on a northerly axial trend. This deformation event produced a tilting of the Mine Sequence to the east in the mine area (Brown, 1986).

3.2.3 Devonian D2 Deformation ...

On a regional scale, Devonian D2 deformation produced a series of open to moderately tight northwest-southeast trending folds with north to northwest trending axial plane cleavages (Williams et al., 1989). In western Tasmania, Devonian granitoids were emplaced during and after Devonian D2 deformation (Berry, 1992).

At Renison, the existence of a large northwest trending anticline has been well documented (Blissett, 1962; Collins, 1972; Patterson, 1979; Patterson *et al.*, 1981; Manly, 1982; Davies, 1985; Brown, 1986 & 1989; Holyland, 1987), however these workers do not agree on the exact location of the hinge zone. Holyland (1987) defined the fold axis as a broad zone of shallow dips, doubly plunging to the north and to the south, lying immediately to the west of the Renison Bell township. Holyland (1987) recognised the progressive, symmetric steepening of the limbs to 50-70°. Alternatively, Lea (1991) argues that bedding dips shallowly throughout the Renison area, steepening only near major faults as a result of drag on these faults.

The sigmoidal contact of the Serpentine Hill Ultramafic complex with the underlying Crimson Creek Formation, to the south of Pine Hill, is considered by Komyshan (1984), Holyland (1987) and Kitto (1994) to result from Devonian D2 folding.

3.2.4 Devonian D3 Dip-Slip Deformation ...

At Renison, Devonian D3 brittle deformation has been linked to the intrusion of the Pine Hill Granite in studies by Kitto (1990), Kitto and Berry (1991) and Kitto (1994). Kitto (1994) computed a near vertical principle stress direction σ_1 and a near horizontal σ_3 trending 238° based on fault striation analysis. These stress tensors do not comply with the regional Tabberabberan stress field and are unique to the Renison region. The granite intrusion initiated normal dextral movement on the Federal-Bassett Fault and the Transverse Faults on the eastern limb of the Renison Bell Anticline (Kitto, 1994).

3.2.5 Devonian D3 Strike-Slip Deformation ...

Kitto (1990 & 1994) recognised dextral wrench reactivation of major normal-dextral faults from overprinting striation relationships. Stress tensors computed from striation data on the Federal-Bassett Fault and miscellaneous fault surfaces by Kitto (1991) indicated a maximum compressive stress σ_1 plunging 12° toward 172° and a near horizontal minimum compressive stress σ_3.

Dextral wrench reactivation produced a dilational jog in the Federal Bassett Fault between intersections with "Shear L" and "Shear P" (Fig. 2.2) and open kink folding with east-west trending axes: (i) on the Renison Horst (Kitto, 1994) and (ii) in the steeply dipping Renison Mine Sequence rocks close to the Federal-Bassett Fault (Marjoribanks, 1989). Kitto (1990 & 1994) interpreted the dextral wrench deformation as occurring in response to the regional Tabberabberan stress field as the local stress field associated with the Pine Hill Granite intrusion decayed. The main episode of mineralisation at Renison has been linked with this deformation (Kitto, *op. cit*).

3.2.6 Post-Devonian (?) Reverse Sinistral Movement ...

Kitto (1990 & 1994) recognised a reverse sinistral reactivation event from overprinting striation relationships. The lack of mineralisation other than calcite associated with this reactivation indicates that it occurred after hydrothermal circulation had ceased. Kitto (*op. cit.*) considered this reactivation occurred in response to local east-west compression and produced displacements of only a few metres.

3.2.7 Tertiary (?) Normal Sinistral Movement ...

Normal-sinistral movement was the final reactivation event recognised from kinematic criteria by Kitto (1990 & 1994) who considered it may have been part of the northeasterly directed extension during the Tertiary period recognised elsewhere in Tasmania (Berry & Banks, 1985; Berry, 1989). This reactivation event produced less than a few metres displacement (Kitto, *op. cit.*).

3.2.8 Relevance of Previous Work to Rendeep Area ...

The Rendeep area is located on the Federal-Bassett Fault, between 800m and

1500m north along strike from the data localities for Kitto's (1990) study (Fig 1.3). It can be assumed, therefore, that brittle reactivations recognised by Kitto (*op. cit.*) for the Federal area (Fig. 1.3) also operated in the Rendeep area in response to the same stress fields with possible minor pertubations due to location with respect to the underlying Pine Hill Granite.

The application of kinematic criteria to resolving the deformational history of the Rendeep area is limited because of the lack of underground openings and oriented drillcore. Some kinematic indicators were recorded on fault surfaces in the 1650 Hangingwall Drill Drive and the Blackwood 1670 Sill access and have been used in this study.

The effects of D3 deformation and associated hydrothermal activity dominate the region close to the Federal-Bassett Fault, hence evidence of earlier deformation is difficult to recognise on a local scale.

3.3 METHOD ...

The first step to resolving the structure of the Rendeep area was to complete a geological interpretation on 25 metre spaced cross sections at 1:1000 scale between 66375m N and 67000m N, from 1000m RL to 1850m RL. These cross sections are presented in Appendix 1. Level plans were also created at 1:500 (above 1550m RL) and 1:1000 scale (below 1550m RL) to cross-check the interpretation. Correlations were drawn between drillholes using an approximate 25m x 25m drill pattern in the upper levels, and greater than 50m x 50m drill pattern in the lower levels. The data spacing is insufficient for confident correlation of minor structures and any interpretation therefore presents an oversimplification of the structure. The interpretation was extended south of the Rendeep area to 65200m N and down to 750m RL on 100m spaced sections so as to include the Deep Federal area (Fig. 1.3) and the top of the Pine Hill Granite beneath the mine. The structural interpretations were digitized and wireframed using Datamine software, creating a three dimensional model which can be rotated allowing the production of those plates shown in this work.

Diamond drill cores and 26 thin sections were examined for textural evidence of the structural history and timing of mineralisation.

Oriented structural data was obtained from the 1650 Hangingwall Drill Drive and Blackwood 1670 sill access.

3.4 PINE HILL GRANITE ...

The petrology and geochemistry of the Pine Hill Granite has been the subject of studies by Groves (1968), Patterson (1979), Ward (1981), Bajwah *et al.* (1991 and in press) and Kitto (1994). Kitto (*op. cit.*) used geochemical data and petrological observations from pevious studies, together with new major, trace and REE analyses, to determine that the Pine Hill Granite was highly fractionated, peraluminous and classified as a reduced ilmenite series (Ishihara, 1977), S-type

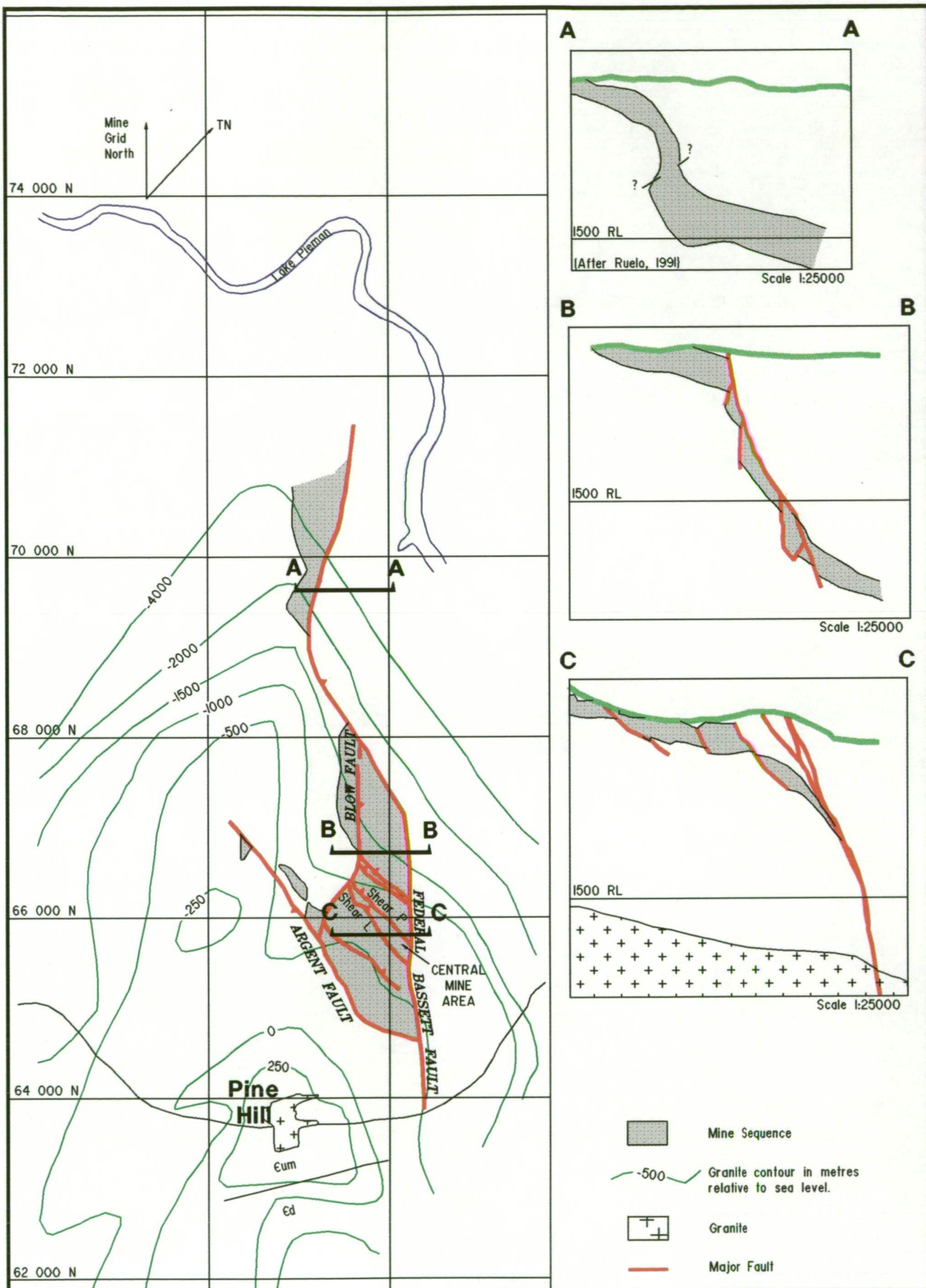
(Chappell & White, 1974) granite.

Kitto (1994) considered that an apophysis of late stage quartz-feldspar porphyry granite beneath the Renison mine generated a high temperature (300-450°C) boron, chlorine and fluorine-rich magmatic fluid which was responsible for tin mineralisation.

3.4.1 Granite Morphology ...

The morphology of the Pine Hill Granite was interpreted by Leaman (1990) from results of a residual gravity survey. A revised interpretation (Leaman, 1994) included specific gravity measurements for representative rock types and additional control from granite intersections in drillholes. Figure 3.1 shows the granite contours from the earlier interpretation with adjustment made for drillhole intersections beneath the Renison mine. The mine is located over the eastern side of a spine in the granite which plunges northwest from its outcrop on Pine Hill. A relatively flat-topped apophysis is located under and just to the east of the central mine area (Fig. 3.1).

Structure contours of drillhole intersections were used to derive the shape of the granite for the three-dimensional model of Rendeep used in this study. There are 9 drillholes that intersect what is considered the main granite body beneath the mine. Drillholes under the Federal area define a relatively flat granite surface. The dip on this surface steepens to 30° to the north beneath the Rendeep area, as defined by drillholes U861, U982, U2748 and S1400 (Plate 3.1). The latter drillhole intersected numerous thin felsic dykes but did not intersect the main granite body.



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FEDERAL-BASSETT FAULT AND CONTOURS

FIGURE 3.1

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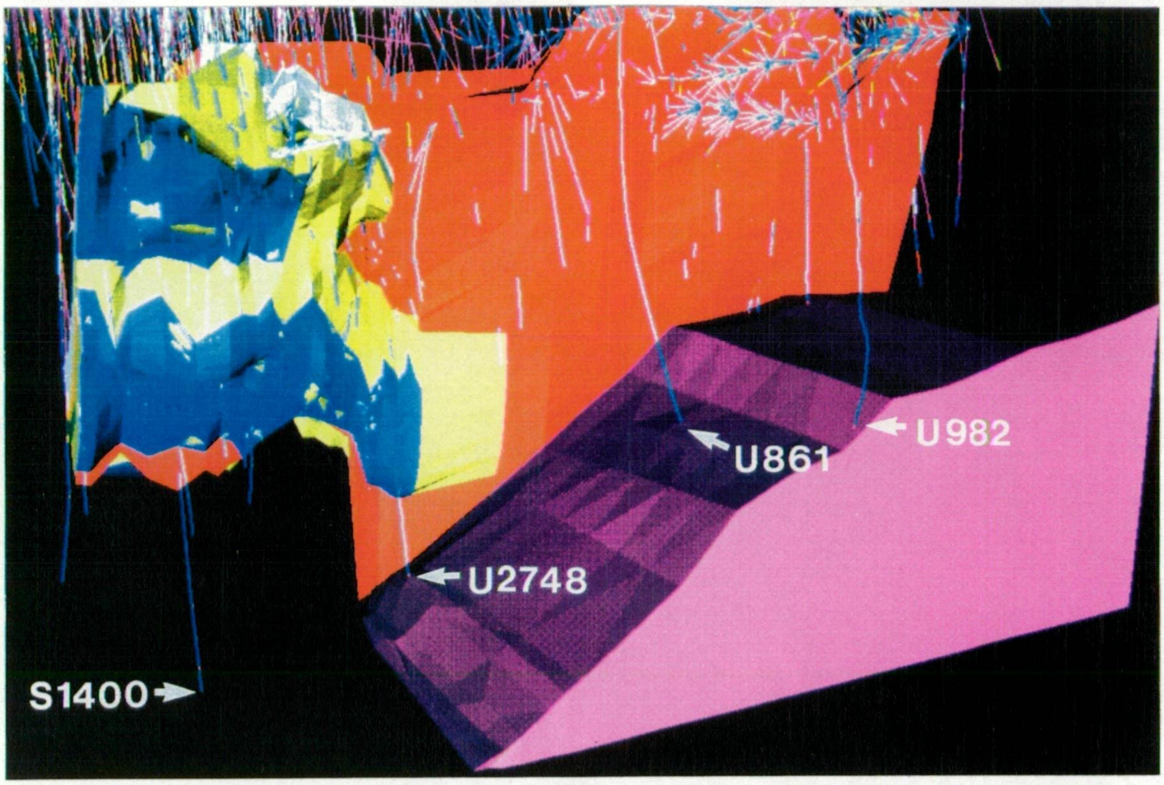


Plate 3.1 3-Dimensional model, looking east-southeast. The granite surface (magenta) is defined by the four indicated drillholes in the northern part of the mine and a cluster of four drillholes under the Federal area (far right). Dimensions of the model are 1775m in north-south direction and 1100m in elevation from 750m RL to 1850m RL.

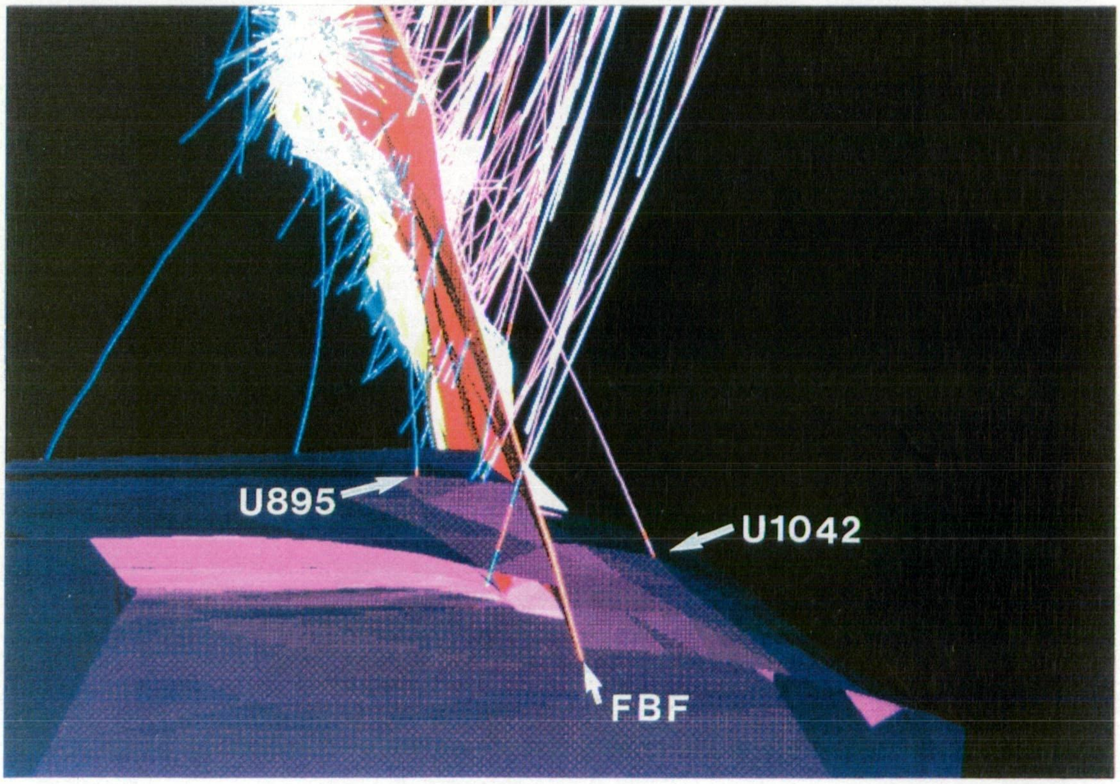


Plate 3.2 3-Dimensional model, looking north along plane of Federal-Bassett Fault (FBF). Drillholes U895, U1042 and others in the deep Federal area define a 75m elevation difference of the granite surface across the Federal-Bassett Fault.

U1042 (65500m N, 44800m E) is the only drillhole to have intersected the granite in the hangingwall of the Federal-Bassett Fault (Plate 3.2). Between U1042 and a group of three drillholes (U895, S391, S391A) in the footwall of the Federal-Bassett Fault there is a difference in elevation of 75 to 100 metres. 280m further north, drillhole S342 (65780m N, 44600m E) intersected the Federal-Bassett Fault in contact with the granite surface.

The difference in elevation of the granite surface across the Federal-Bassett Fault is interpreted as being due in part to displacement of the granite by the fault, i.e the fault penetrates below the granite surface. The significance of this in terms of the timing of mineralisation is discussed in Chapter 4, Section 4.9.2.

3.4.2 Textural observations of granite margins ...

Drillhole U2748 (Plate 3.1) intersected several felsic dykes up to 150m above the Pine Hill Granite, similar to those in drillhole S1400 (Section 3.4.1, Plate 3.1), before intersecting the main granite body(?) at 820m RL. The dykes showed evidence of tensile opening of the hornfelsed country rock (Plate 3.3). The contact with the overlying hornfelsed Dalcoath Member sediments with the main granite body was sharp and undulose (Plates 3.5 and 3.6). There was a 30cm chilled margin to the granite and equivocal evidence for the melting of country rock.

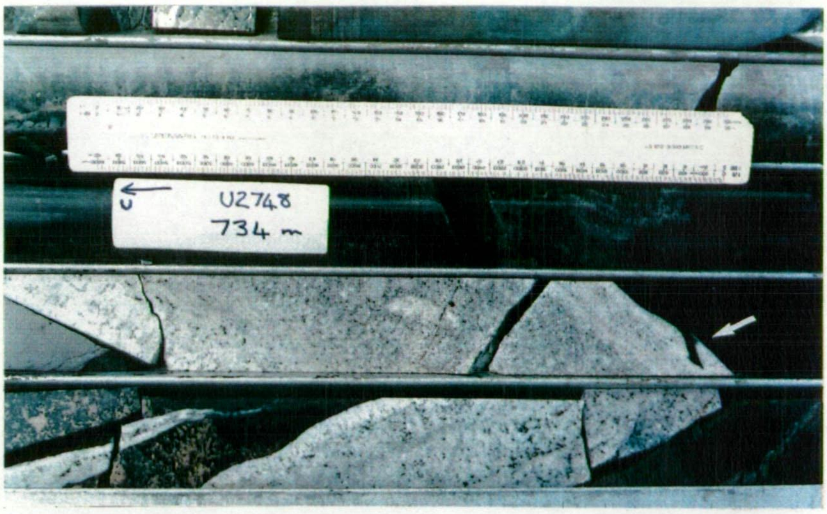


Plate 3.3 Chilled granitic dykes intruding hornfelsed Dalcoath Member sediments showing evidence of tensile opening (arrow). Drillhole U2748, 734m.

Plate 3.4 Contact between hornfelsed Dalcoath Member sediments and the main Pine Hill Granite body (?), drillhole U2748, 840.6m. The drillhole was terminated after intersecting 11m of granite.

Plate 3.5 Closeup of contact (arrow) in Plate 3.4. The chilled margin of the granite extends for about 30cm from the contact.

3.4.3 Intrusive Mechanism ...

Kitto (1994) considered the Pine Hill Granite to have been emplaced initially by passive means, followed by a process of upward displacement of host sequences as the intrusion reached shallow (2-4km) depths. Emplacement occurred at solidus temperatures less than 650°C (Bajwah *et al.*, in press).

The numerous felsic dykes in drillholes U2748 and S1400 beneath the Rendeep area propagated due to tensile stresses created by the magma pressure exceeding the lithostatic pressure and to differential thermal expansion in the contact metamorphic aureole. Dyke propagation may assist stoping of the host rock as suggested by Patterson *et al.* (1992). The lack of evidence for melting of country rock confirms estimates for relatively low temperatures and shallow depths for the intrusion and predominantly forceful emplacement mechanisms (Kitto, 1994).

Processes by which the host rock can accommodate an intrusion at relatively shallow levels are: (1) roof lifting along extensional faults or doming, (2) stoping, (3) downward host rock return flow, and/or (4) development of a concentric flattening strain in the contact metamorphic aureole (Patterson *et al.*, 1992). Evidence for accommodation of the Pine Hill Granite predominantly by process (1) is presented in subsequent sections.

3.5 NORTH BASSETT STRUCTURE ...

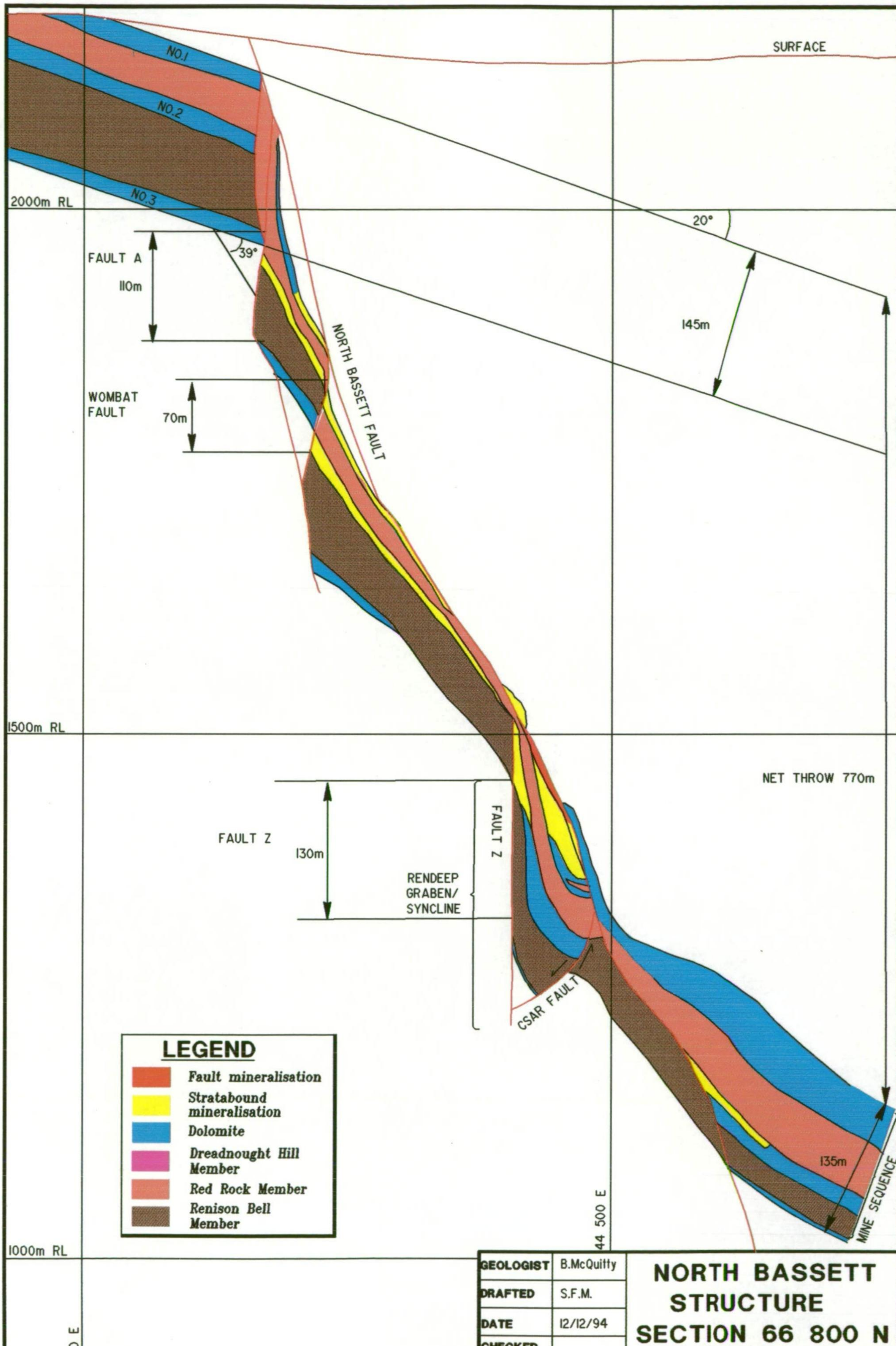
The North Bassett Structure refers to the northern segment of the Federal-Bassett Fault north of the projected contact with "Shear P" (Fig. 3.1). The structure is a complex zone of folding and faulting representing a transition from monoclinal folding to the north, to normal faulting in the central mine area (Fig. 3.1). The transition in structural style accompanies a shallowing of the Pine Hill Granite to the south.

A typical section through the North Bassett Structure is shown in Figure 3.2. The Mine Sequence has undergone what approximates to simple shear (Kitto, 1991), producing a rotation of 39° toward the plane of the North Bassett Fault. The net throw on the structure of 770m is the sum of the throw on individual faults (325m), rotation and other brittle and ductile components. Figure 3.3 shows a reconstruction of cross section 66800m N through the North Bassett Structure with the dip and rotation component removed. Similarities with a rifting extensional model including flats and ramps in the footwall structure and a rollover anticline in the hangingwall are apparent. Brittle and ductile components of deformation in the North Bassett Structure are defined and described below.

3.5.1 Brittle Deformation ...

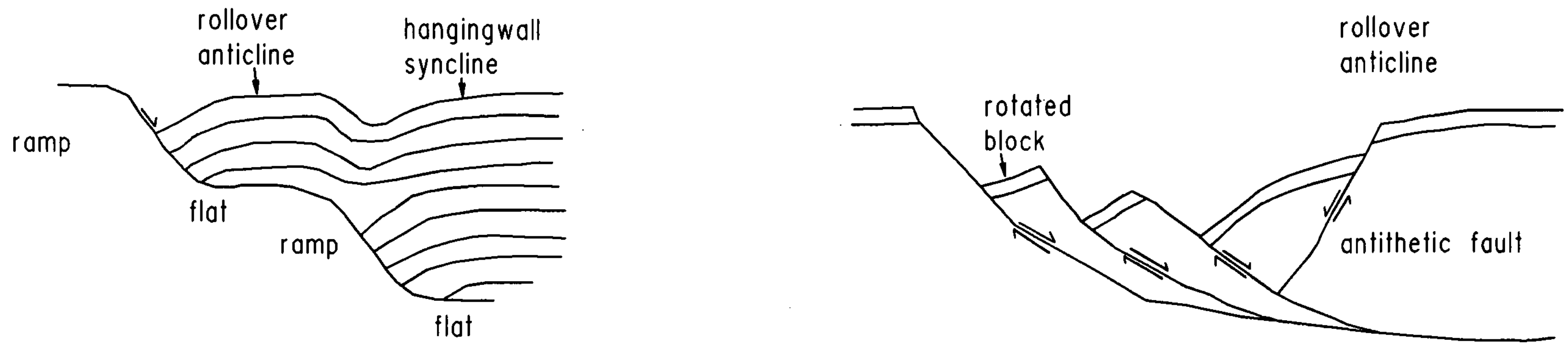
3.5.1.1 North Bassett Fault ...

The North Bassett Fault forms the hangingwall of the North Bassett Structure and is

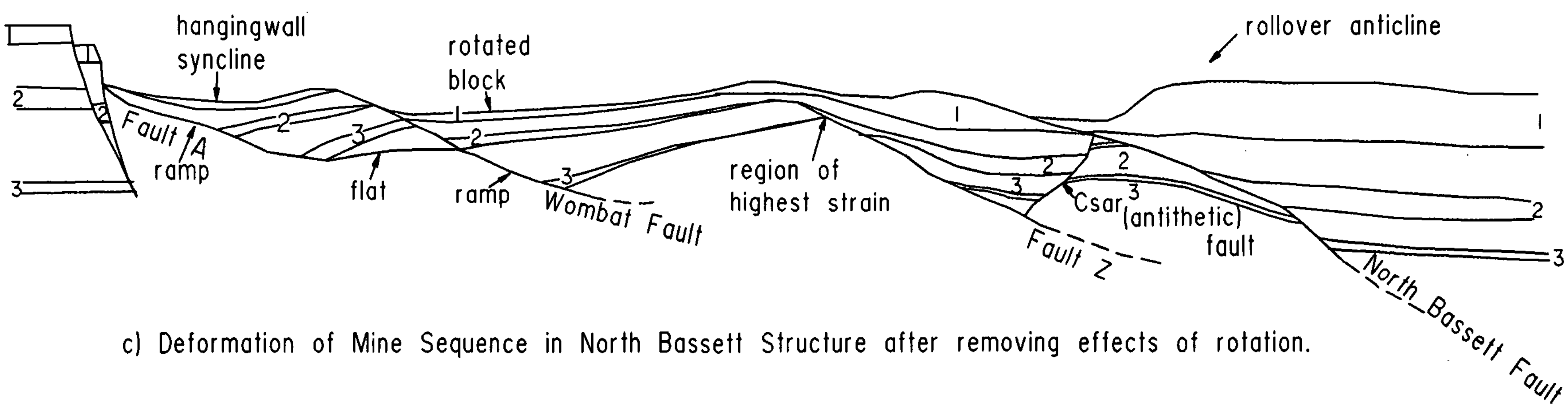


NORTH BASSETT STRUCTURE SECTION 66 800 N

FIGURE 3.2



a) and b) Features of extension (rifting) terranes after Gibbs (1984)



c) Deformation of Mine Sequence in North Bassett Structure after removing effects of rotation.

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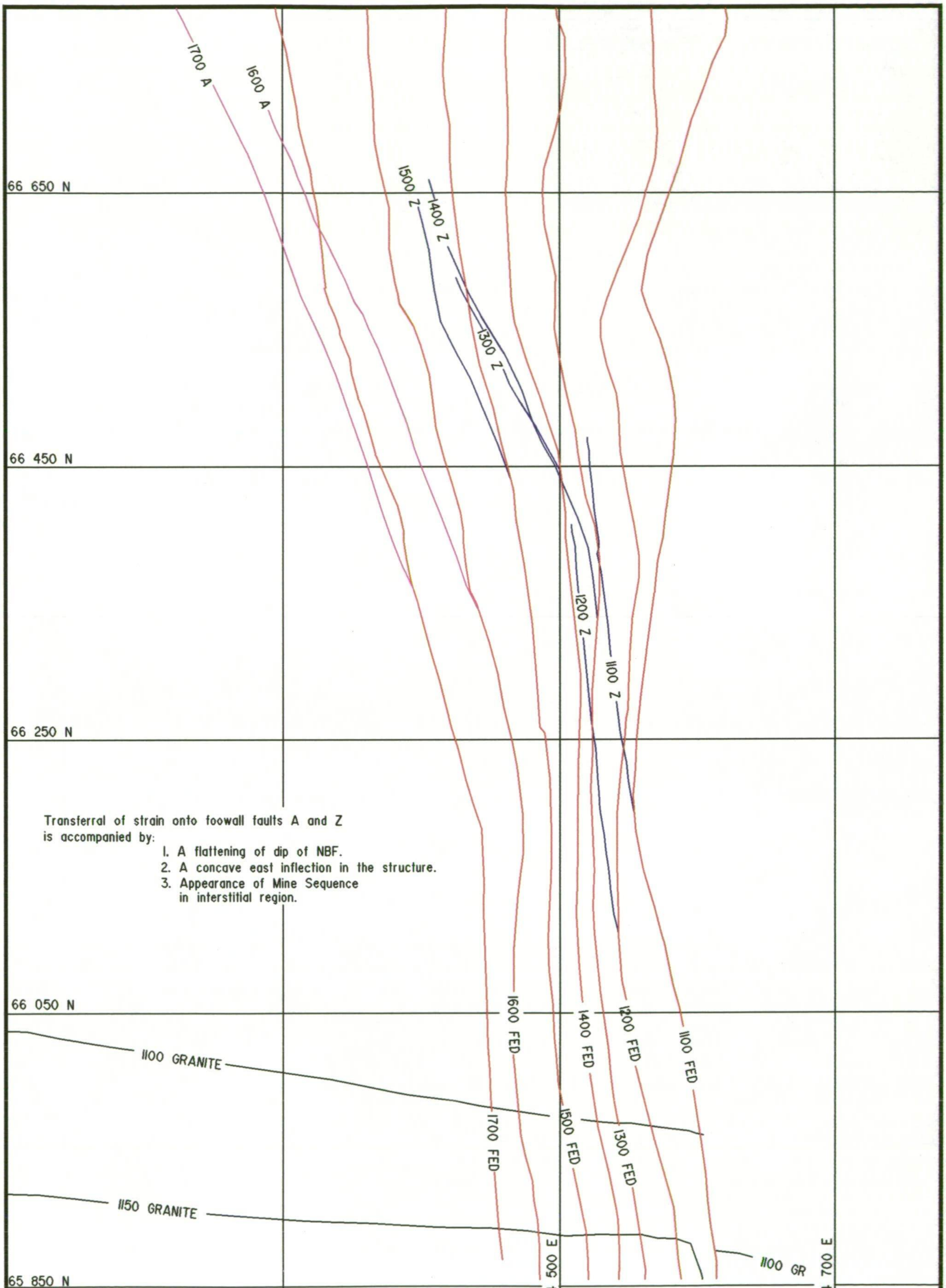
COMPARISON OF NBS WITH RIFTING MODEL

FIGURE 3.3

C:\DRAFTED\GEOLOGY\PROJECTS\RENDEEP\RPI7194\RENDO082 continuous with the Federal-Bassett Fault in the central mine area. It consists of a zone of intense shearing and brecciation from 0.6 to 18m wide, in which fissure infill mineralisation has developed. The mineralised fissures anastomose and are offset in en-echelon fashion on a scale of a few metres but on a broader scale the structure can be considered planar and continuous over at least a 2 km strike length. The structure dips between 65° and 78° toward 55° near 66400m N, and towards 90° north of 66700m N, relative to the Renison mine grid (RMG). This represents a concave east inflection on the North Bassett Fault, north of 66400m N (Fig. 3.4; Plate 3.6).

The Renison Mine Sequence exists on both sides of the North Bassett Fault below about 1400m RL on section 66800m N, as shown in Figure 3.5. In this region the North Bassett Fault is greatly reduced in width, has a throw of the order of 30m or less and shows some tendency to flatten sub-parallel to bedding. Below the Mine Sequence the North Bassett Fault becomes difficult to correlate, due to the absence of marker horizons in the Dalcoath Member and to the lack of drilling. Single or multiple, anastomosing mineralised tension gashes and breccias occur at the expected location of the North Bassett Fault in the more massive lithologies, compared to a more planar structure in the contrasting rheologies of the Renison Mine Sequence.

For much of its length the North Bassett Fault occupies the stratigraphic position of the No.1 Horizon, faulting the Red Rock Member against the overlying Dreadnought Hill Member. Talc clasts and massive pyrrhotite mineralisation in some sections of



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STRUCTURE CONTOURS OF FAULTS A,Z & NBF

FIGURE 3.4

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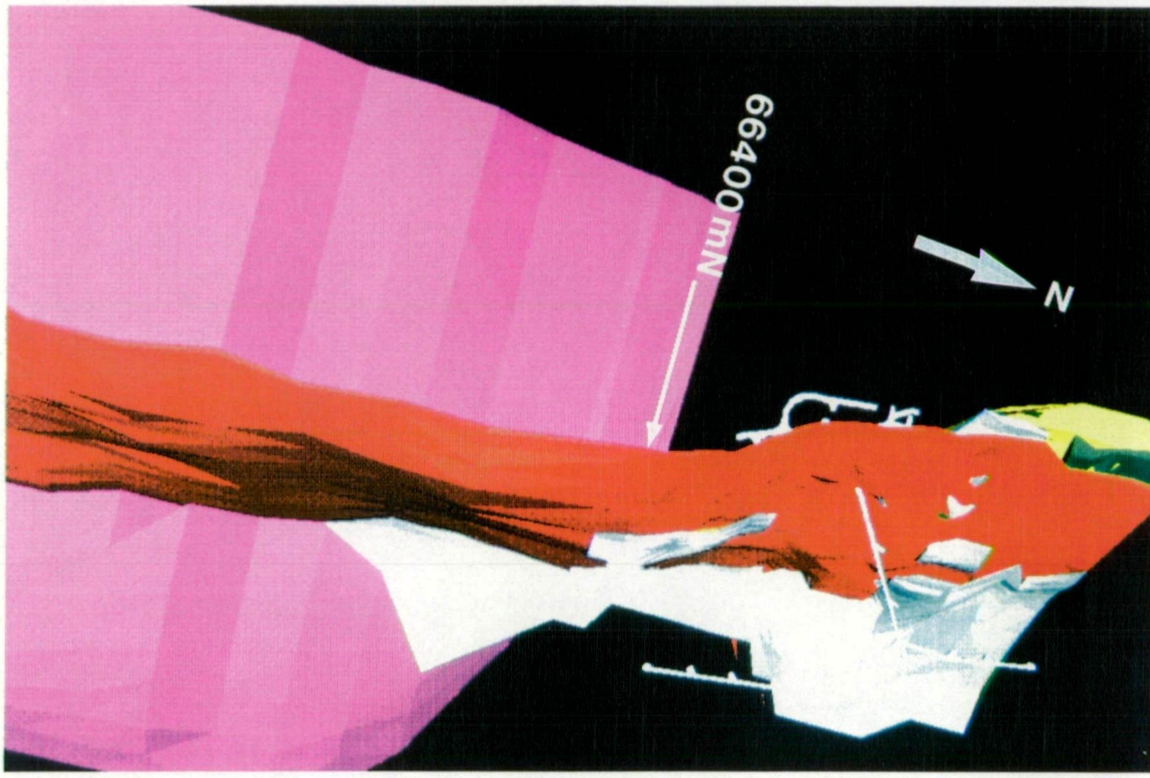
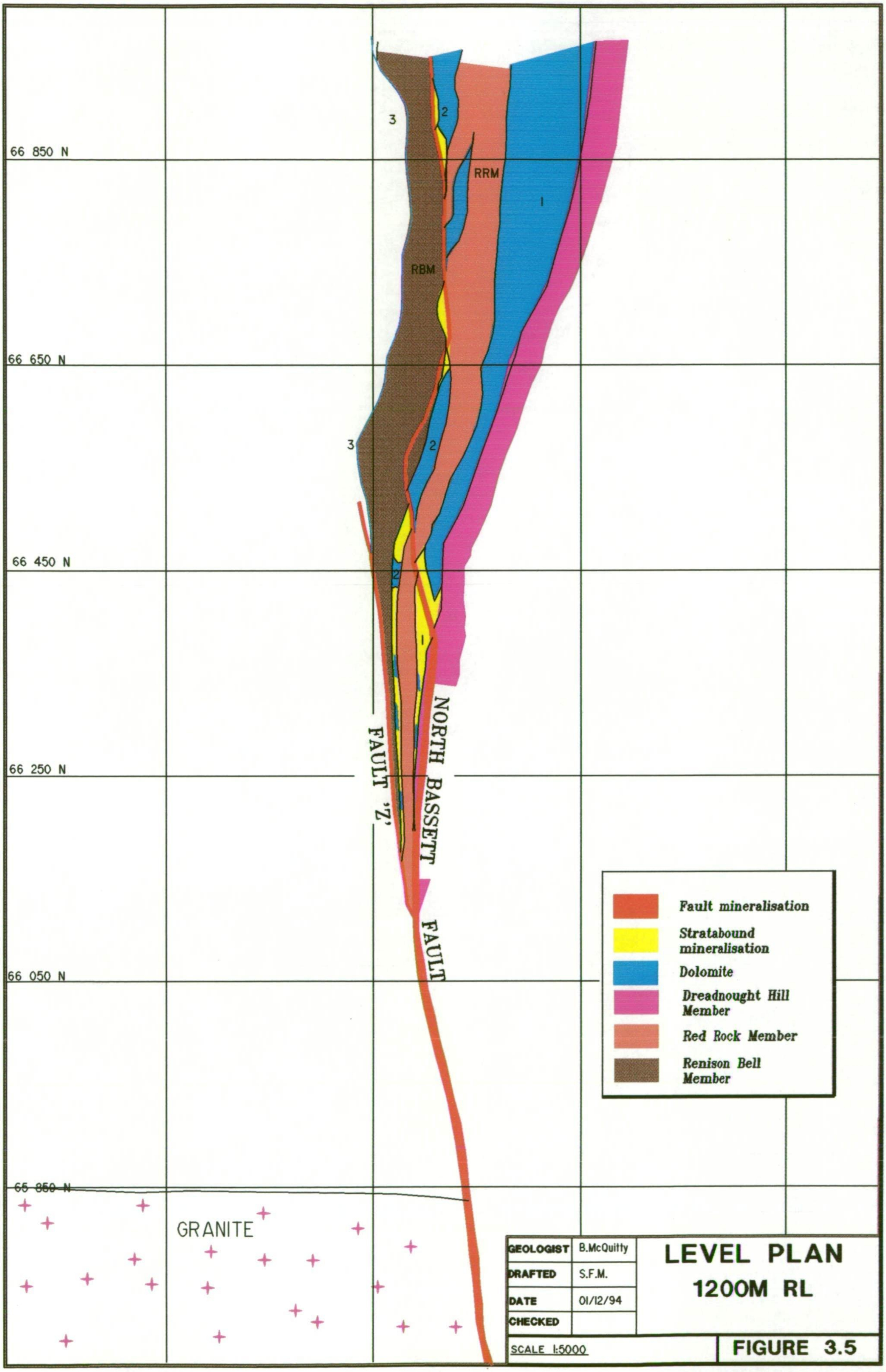


Plate 3.6 3-Dimensional model in plan view. A concave east inflection in the North Bassett Fault (red) develops north of 66400m N. The No. 1 Horizon (white) is shown draping the hangingwall (eastern) side of the fault.



66 850 N
66 650 N
66 450 N
66 250 N
66 050 N
65 850 N
3
2
RRM
1
RBM
3
2
2
1
NORTH BASSETT
FAULT
FAULT 'Z'
GRANITE
Fault mineralisation
Stratabound mineralisation
Dolomite
Dreadnought Hill Member
Red Rock Member
Renison Bell Member
GEOLOGIST B.McQuitty
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LEVEL PLAN
1200M RL
FIGURE 3.5
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No.2 Horizon True Thickness vs Distance from North Bassett Fault

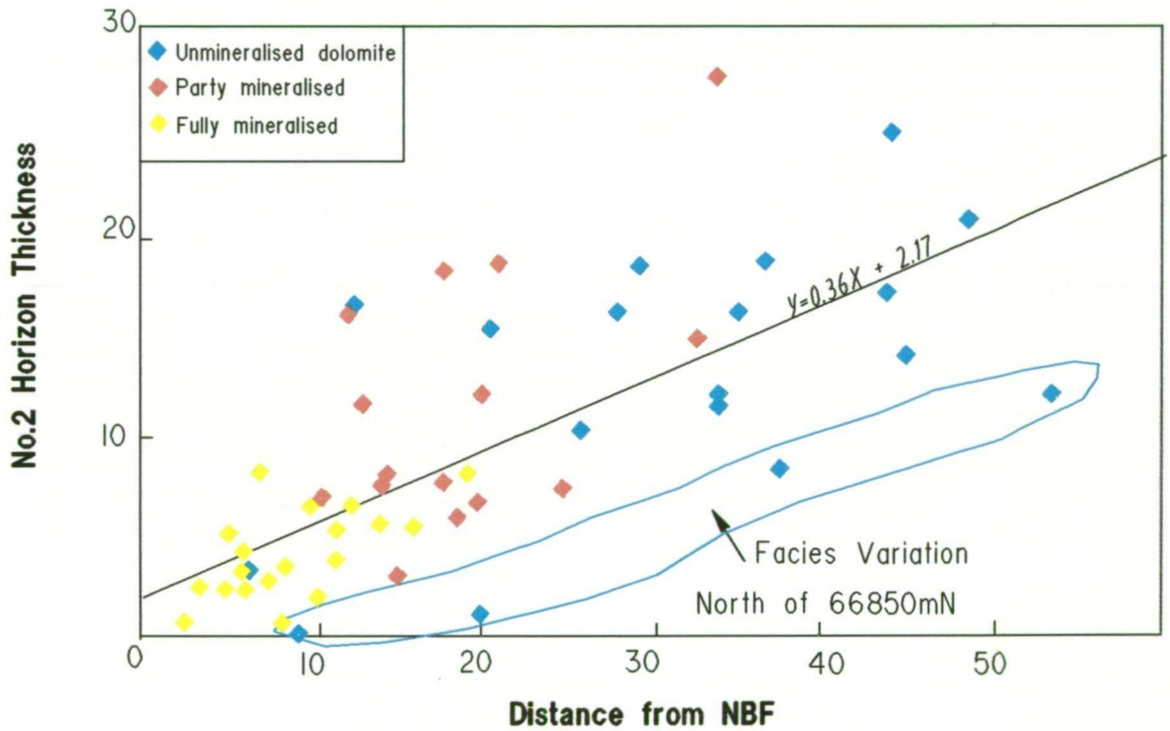


Figure 3.6

the fault are interpreted as replaced No.1 Horizon dolomite, entrained into the fault.

The structural interpretation (Appendix 1) shows a thinning of all stratigraphic horizons towards the North Bassett Fault. A plot of No. 2 Horizon true thickness vs. distance from the North Bassett Fault was made to further investigate this phenomenon (Fig. 3.6). The No. 2 Horizon was chosen because it is one of the most continuous horizons in the Rendeep area and generally has well defined margins. The relationship appears linear, with a coefficient of determination (r^2) of 0.51, indicating a fairly broad spread of data. The effect of possible facies variation north of section 66850m N, (Chapter 2, Section 2.6) stands out as four abberrant points.

The linear relationship in Figure 3.6 indicates that the observed thinning must be the result of structural processes, and implies that the North Bassett Fault is the principal plane of shearing in the North Bassett Structure. The distribution of stratabound mineralisation about the North Bassett Fault, as shown in Figure 3.6 and in Appendix 1, indicates that it was also the main mineralising conduit. There is some suggestion from Figure 3.6 that mineralisation may have accompanied the thinning or that volume loss during mineralisation produced the thinning as proposed by Holyland (1987). This possibility is discussed further in Sections 3.5.1.6 and 3.5.2.4.

3.5.1.2 Footwall Faults ...

Two major sub-vertical faults, Faults A and Z, form the footwall structures to the

North Bassett Structure (Fig. 3.2). The Wombat Fault, another major fault with a 70m throw occurs between Fault A and the North Bassett Fault and dips steeply west. Faults A and Z strike at approximately 155° (RMG), diverging westward from the North Bassett Fault to the north of their projected contacts (Fig. 3.4). The strike of Fault Z turns to sub-parallel that of the North Bassett Fault north of 66700m N. Faults A and Z steepen and diverge from the North Bassett Fault with depth (Fig. 3.2). In the vicinity of section 66700m N (Appendix 1) Fault Z displays a pronounced west flattening of dip.

Faults A and Z are difficult to locate below their respective contacts with the Renison Mine Sequence due to the lack of drilling and to the absence of marker horizons in the Dalcoath Member which indicate fault displacements. Limited evidence (e.g. drillhole U2872, Appendix 1, Section 66700m N) shows a decrease in intensity of shearing on Fault A with depth due to strain transferral to bedding plane slip in the overlying Renison Mine Sequence (Chapter 2, Section 2.6). Over much of its length Fault Z occupies the stratigraphic position of the No. 3 Horizon, faulting the well-bedded Renison Bell Member against the Dalcoath Member.

Fault A is exposed in the 1650 Cross-cut, Romulus 1900, the North Renison Decline and Blackwood 1670 sill access (Fig. 1.3). In all but the latter it consists of about a metre wide zone with foliated, cohesive ductile fabric cut by single or multiple, anastomosing sub-vertical brittle planar faults with predominantly horizontal striations. In the latter it is a double structure, separated by 4 metres of sheared, silicified shale with en-echelon quartz veins (Fig 2.3; Plate 3.7). The hangingwall

Plate 3.7 Fault A exposure in Blackwood 1670 Sill access, left wall. Fault drag produces a steepening of bedding in the well bedded upper Renison Bell Member (RBU). Fault A is locally a double structure, separated by 4m of sheared silstsone and sandstone impregnated with quartz veins which dip steeply northeast.

structure, 400mm wide, is infilled with quartz and disseminated pyrrhotite. The effect of fault drag on the dip of the upper Renison Bell Member and the 2.2 Horizon dolomite is shown in Plate 3.7. Although Fault A is mineralised locally, mineralisation has not spread to replace the 2.2 Horizon dolomite.

Drillcore specimens and thin sections of Faults A and Z in Dalcoath Member or Renison Bell Member rocks consists of quartz sandstone clasts in various stages of recrystallisation within a fine grained tourmalinite and/or carbon matrix containing variable development of quartz augen and C and S fabric (Plates 3.8, 3.9, 3.10 & 3.11). Later pyrrhotite-quartz cut the earlier ductile fabric (Plates 3.8 & 3.9). The specimens generally classify as protomylonite using the classification system for faulted rocks developed by Sibson (1977). Similar fabrics have been recorded in contact metamorphic aureoles elsewhere. Rubenach and Bell (1988) described mylonitic carbonaceous metapelites formed synchronously with the emplacement of granitoids in the contact metamorphic aureole of the Tinaroo Batholith, northern Queensland.

Plates 3.12, 3.13, 3.14 and 3.15 show a transition in deformational fabric in Faults A and Z from a predominantly brittle pull-apart texture in carbonaceous meta-sandstone, 730m from the Pine Hill Granite (Plate 3.12), to a well developed C and S fabric in protomylonite, 530m from the Pine Hill Granite. The increase in ductility accompanies an increase in the amount of recrystallisation of quartz in quartz sandstone clasts.

Plate 3.8 Fault A: foliated quartz-tourmalinite with development of quartz augen (a), cut by pyrrhotite stringers. Drillhole U2099, 35.9m, section 66500m N, 1650m RL.

Plate 3.9 Fault Z: foliated, tourmalinised shale and sandstone with development of quartz augen (a), cut by a quartz-pyrrhotite vein (v). Drillhole U2719, 267.3m, 66600m N, 1450m RL

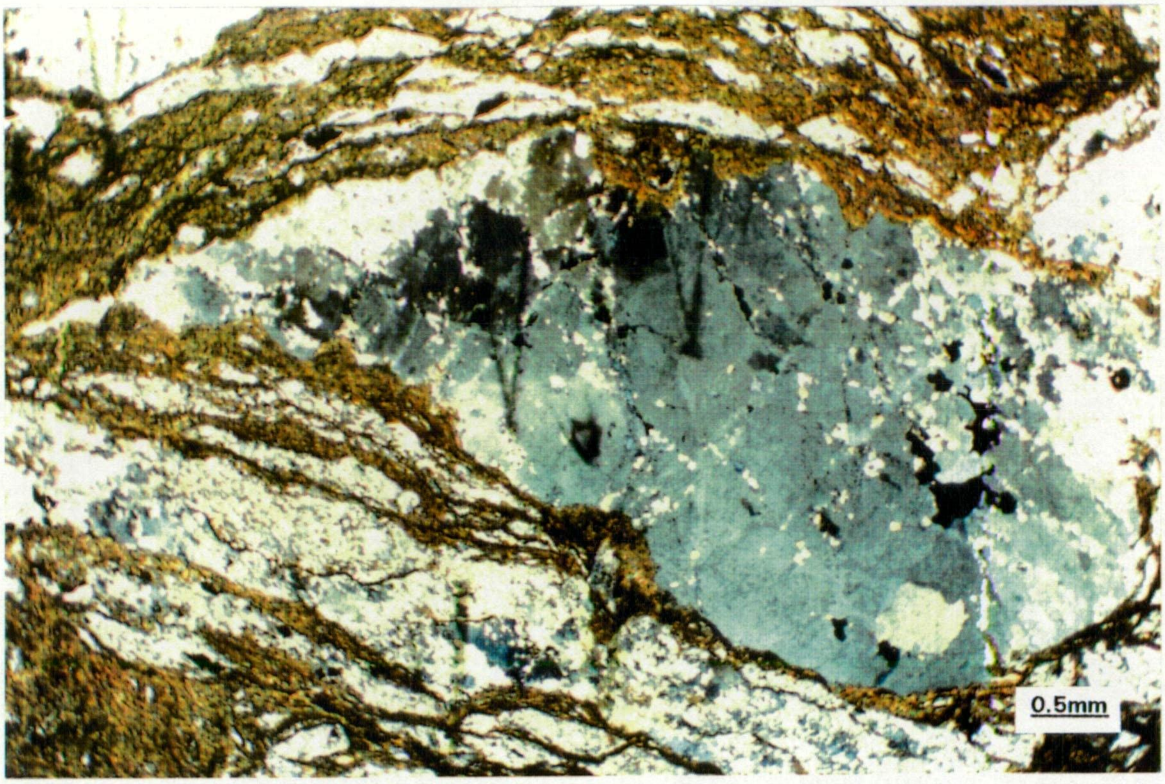


Plate 3.10 Fault A: quartz tourmalinite showing part of large quartz augen (5mm long) displaying undulose extinction. Matrix is fine brown tourmaline (dravite). Quartz sandstone lamellae have recrystallised. Drillhole U2264, 18.9m, 66575m N, 1650m RL. X-Polars.

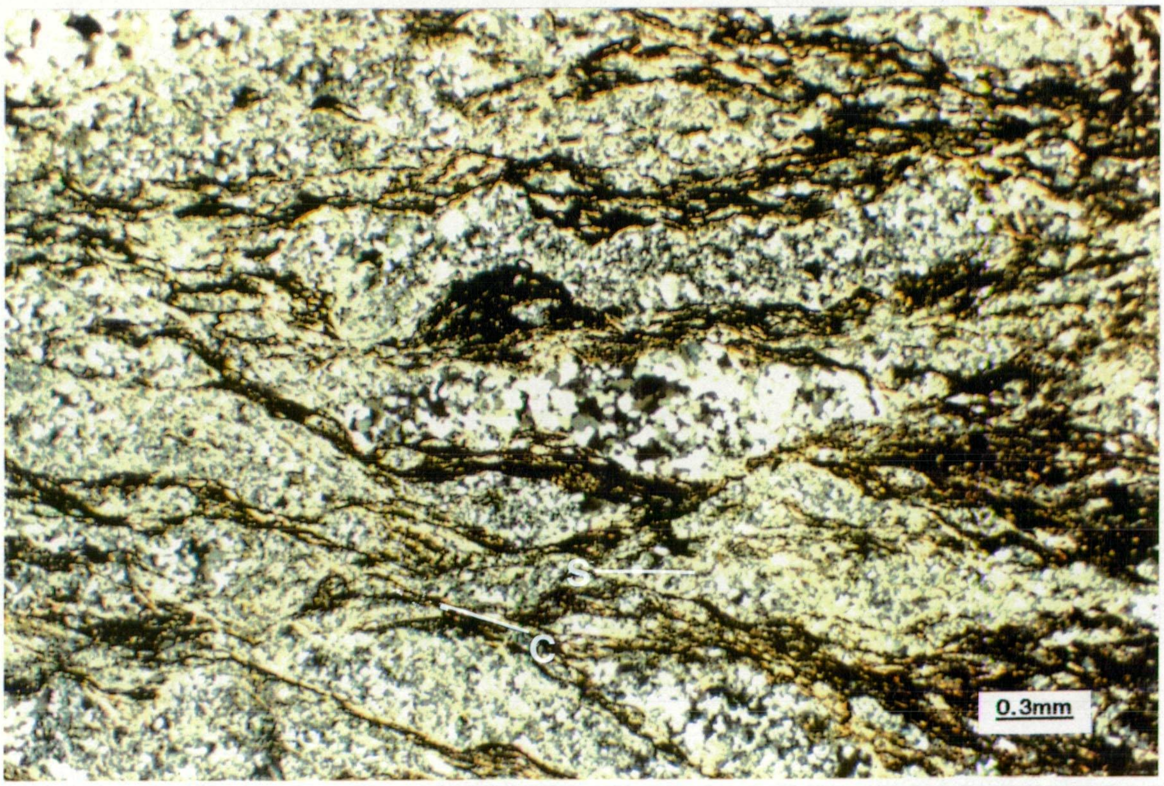


Plate 3.11 Fault Z: quartz sandstone with well developed C and S fabric and development of quartz augen by recrystallisation of sandstone clasts. Matrix is fine grained dravite and carbon. drillhole U2736, 299.8m, 66550m N, 1400m RL. X-Polars.

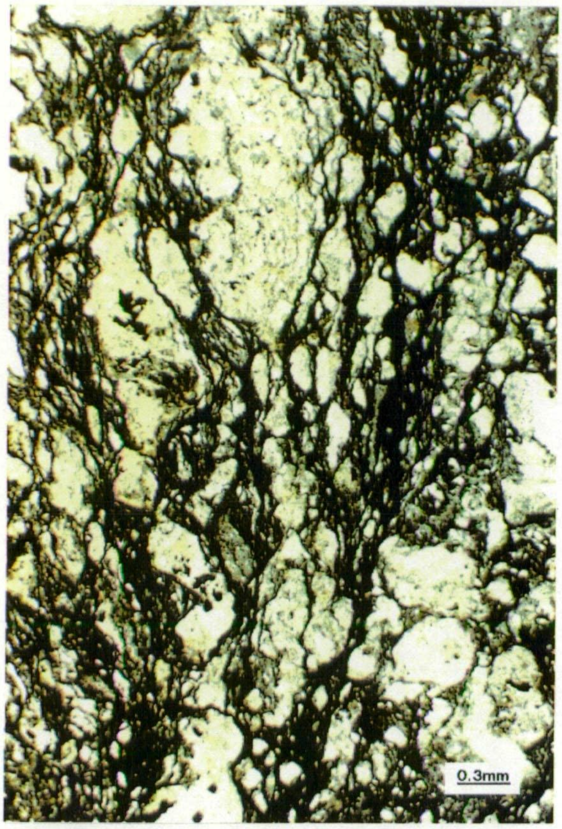


Plate 3.12 Fault Z: pull-apart texture in meta-sandstone. Drillhole U2530, 203.6m, 66750m N, 1480m RL. 730m from granite. Plane polarised light.

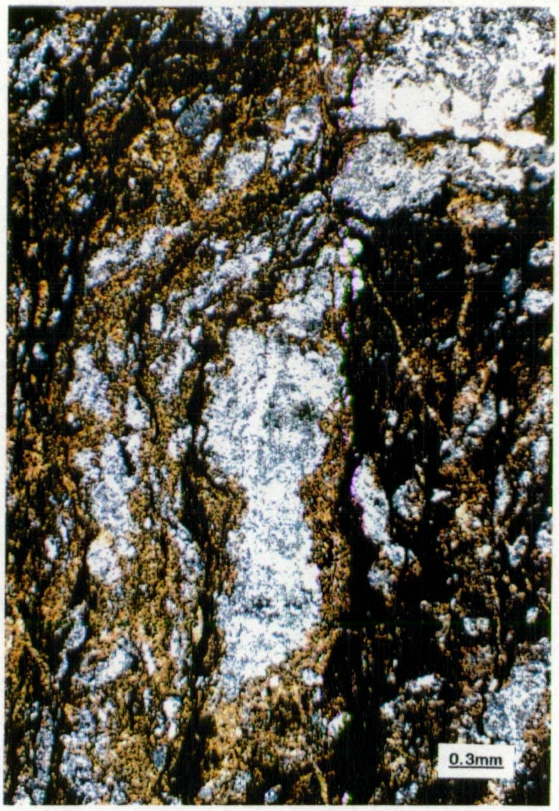


Plate 3.13 Fault A: quartz-tourmalinite. Drillhole U2396, 146.9m, 66525m N, 1600m RL. 670m from granite. X-polars.

Plate 3.14 Fault Z: moderately developed C and S fabric in partly recrystallised meta-sandstone. Drillhole U2719, 267.3m, 66600m N, 1450m RL. 600m from granite. X-polars.

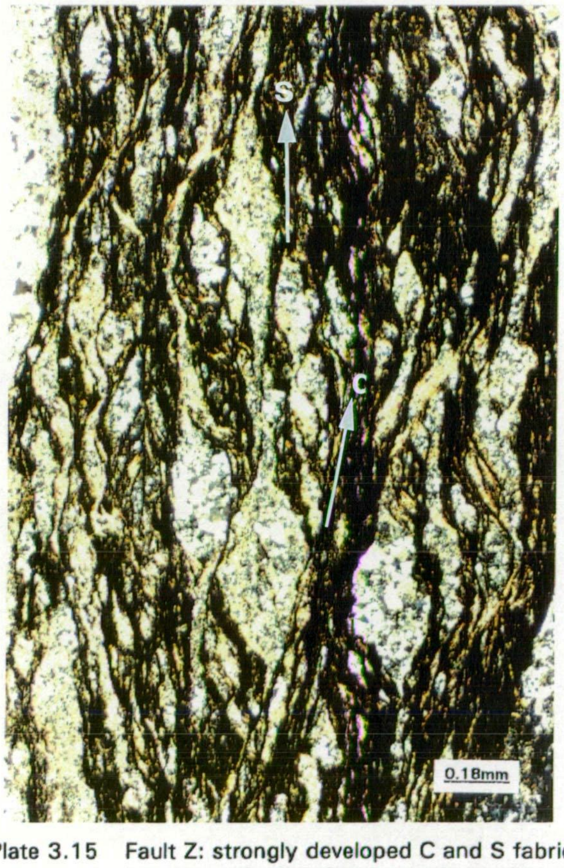
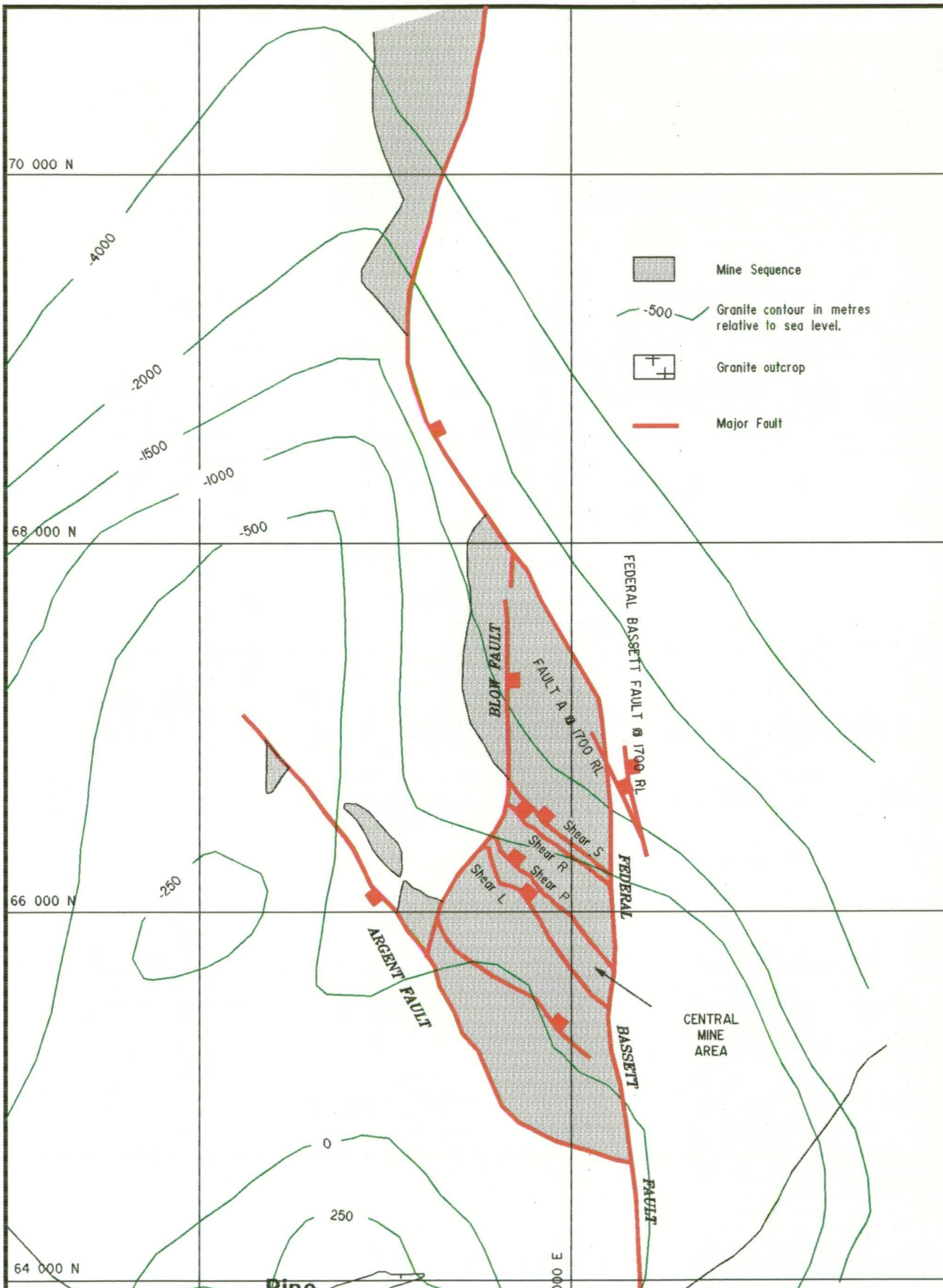


Plate 3.15 Fault Z: strongly developed C and S fabric in proto-mylonite. Some minor rotation of clasts has occurred. Drillhole U2736, 299.8m, 66550m N, 1400m RL. 530m from granite. X-polars.



PLAN VIEW OF MAJOR FAULTS AND GRANITE CONTOURS

FIGURE 3.7

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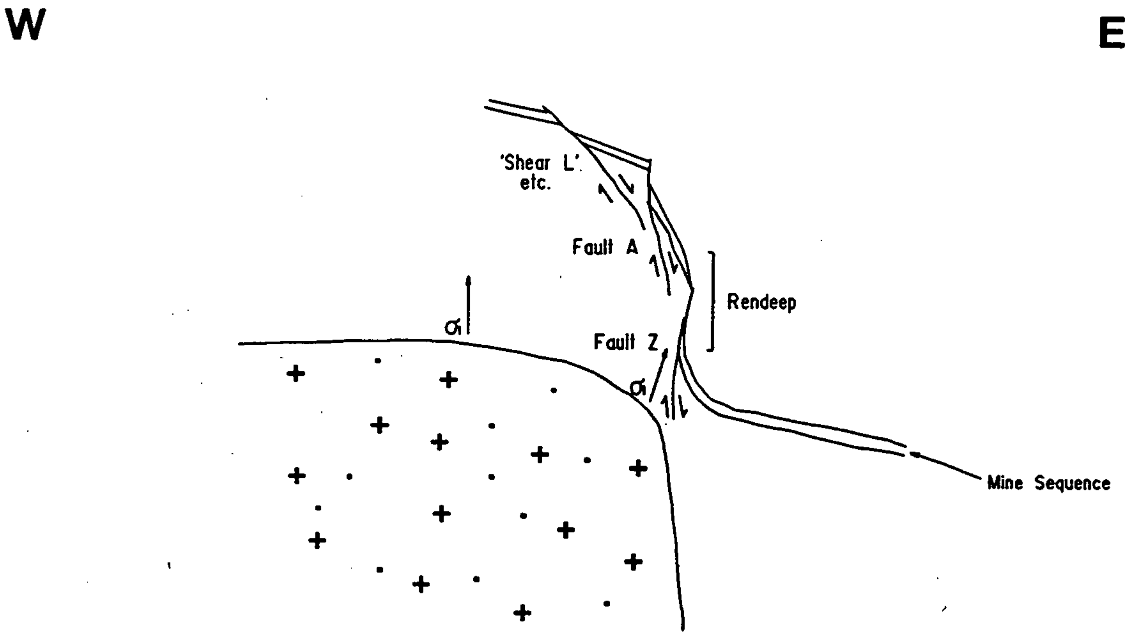
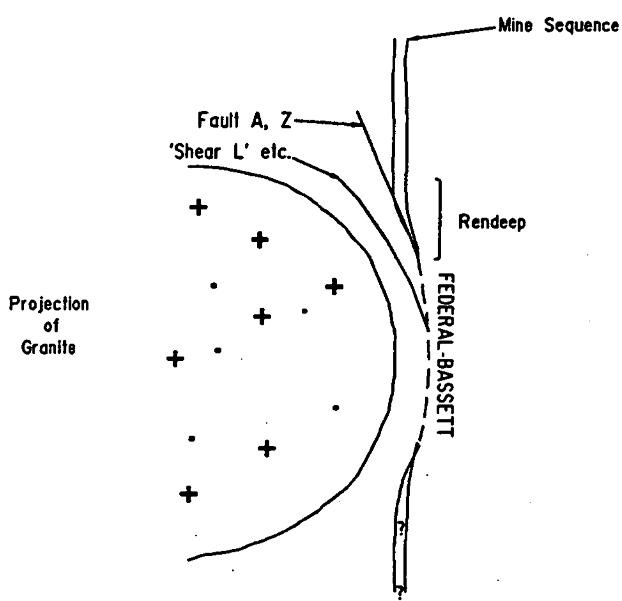


A) Section



B) Plan

Diagram illustrating relationship of Transverse Faults to radial stress field around Pine Hill Granite

GEOLOGIST	B.McQuilty	RELATIONSHIP OF FAULTING TO PINE HILL GRANITE (SCHEMATIC)
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SCALE 1:NOT TO SCALE		FIGURE 3.8

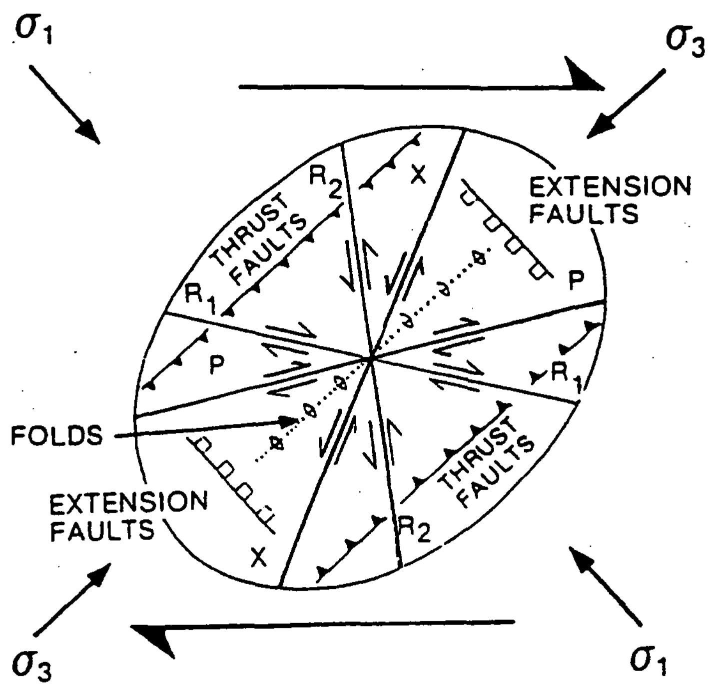


Fig. 3.9 Regional strain ellipse associated with a wrench/strike-slip fault system. The Reidel shear faults are the synthetic R_1 and antithetic R_2 systems (in most cases displacements are minor on these faults). In some systems synthetic P and antithetic X shears may also develop. Folds and contraction (thrust) faults are developed at 90° to σ_1, whereas extension (normal) faults are developed 90° to σ_3. (From McClay, 1987).

The strike of Faults A and Z parallels the contours of the underlying Pine Hill Granite (Kitto, 1992; Fig. 3.7). They are the northernmost of the set of Transverse Faults including "Shears" L, P, etc. (Chapter 1, Section 1.2) which formed during Devonian D3 deformation in response to arching of the Mine Sequence over the eastern shoulder of the apophysis of Pine Hill Granite beneath the Renison Mine (Kitto, 1994, Fig. 3.8). The Wombat Fault, formed between Fault A and the North Bassett Fault, acting as a duplex pair, in a Reidel R1 orientation (Fig.3.9), approximately 30 degrees to the subvertical principle stress direction during granite intrusion. In plan view, (Figs. 3.5 & 3.8) Faults A, Z and the North Bassett Fault act to produce a necking of the interstitial Renison Mine Sequence to the south, as it approaches the Pine Hill Granite. Neither Fault A nor Fault Z show evidence of being significant conduits for mineralising fluids.

3.5.1.3 Antithetic Faults - Csar Fault ...

The Csar Fault (Fig. 3.2) is inferred from offsets in the Renison Mine Sequence north of section 66750m N. The fault subparallels drillholes and is rarely intersected. The only intersection is in drillhole U2523 (Plate 3.16), where a fault consisting of about 10cm of brittle, chlorite-lined fault breccia with oblique slickensides shortens the Renison Bell Member to 10m thickness. Reconstruction of drillcore segments shows the fault surface dips westerly in a direction opposite to that of the bedding.

The Csar Fault develops in the axis region of a syncline between sections 66650m N and 66750m N (Appendix 1). The syncline is inferred from displacements of the

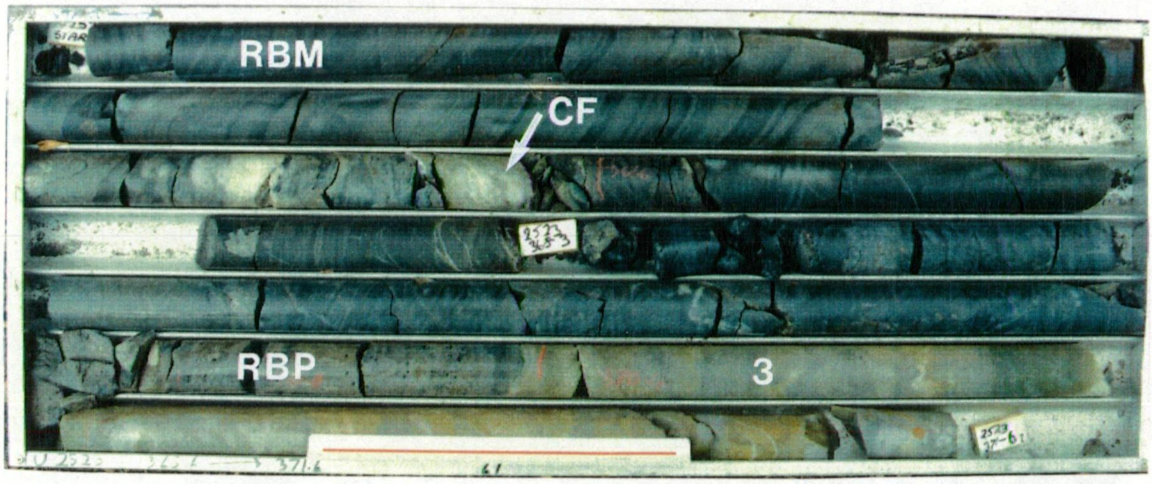


Plate 3.16 Intersection of Csar Fault (CF) in drillhole U2523, 367.5m. The fault occurs just 7m below the No. 2 Horizon intersection and shortens the Renison Bell Member (RBM) to 10m thickness. Renison Bell Member pebble beds (RBP) are shown overlying the No. 3 Horizon (3). Dip direction of the fault has been established as opposite that of the bedding. The scale is 30cm.

Renison Mine Sequence between drillholes. Displacement increases north of section 66750m N, reaching a maximum of between 15 and 25 metres near 66825m N, where faulting must be present to account for the offset. The transition from fold to fault, south to north, is further evidence of the zonation of brittle to ductile deformation approaching the Pine Hill Granite, referred to in the previous section.

3.5.1.4 Rendeep Graben/Syncline ...

The Csar Fault forms the lower part of a graben structure, bounded to the west and updip by Fault Z (Fig. 3.2). The graben structure is here termed the "Rendeep Graben" or alternatively the "Rendeep Syncline" where the Csar Fault is not present. The Rendeep Graben/Syncline is associated with the rotation of the dip of the Renison Mine Sequence from 30° E in the hangingwall of the North Bassett Structure to sub-vertical and draped along Fault Z. The large thickness of Renison Mine Sequence developed in the axis region of the Rendeep Graben/Syncline suggests that this was a region of low strain, relative to the regions above and below and consequently developed as a dilational site north of 66750m N (Appendix 1) for the focussing of hydrothermal fluids, a relationship that is explored further in Chapter 4.

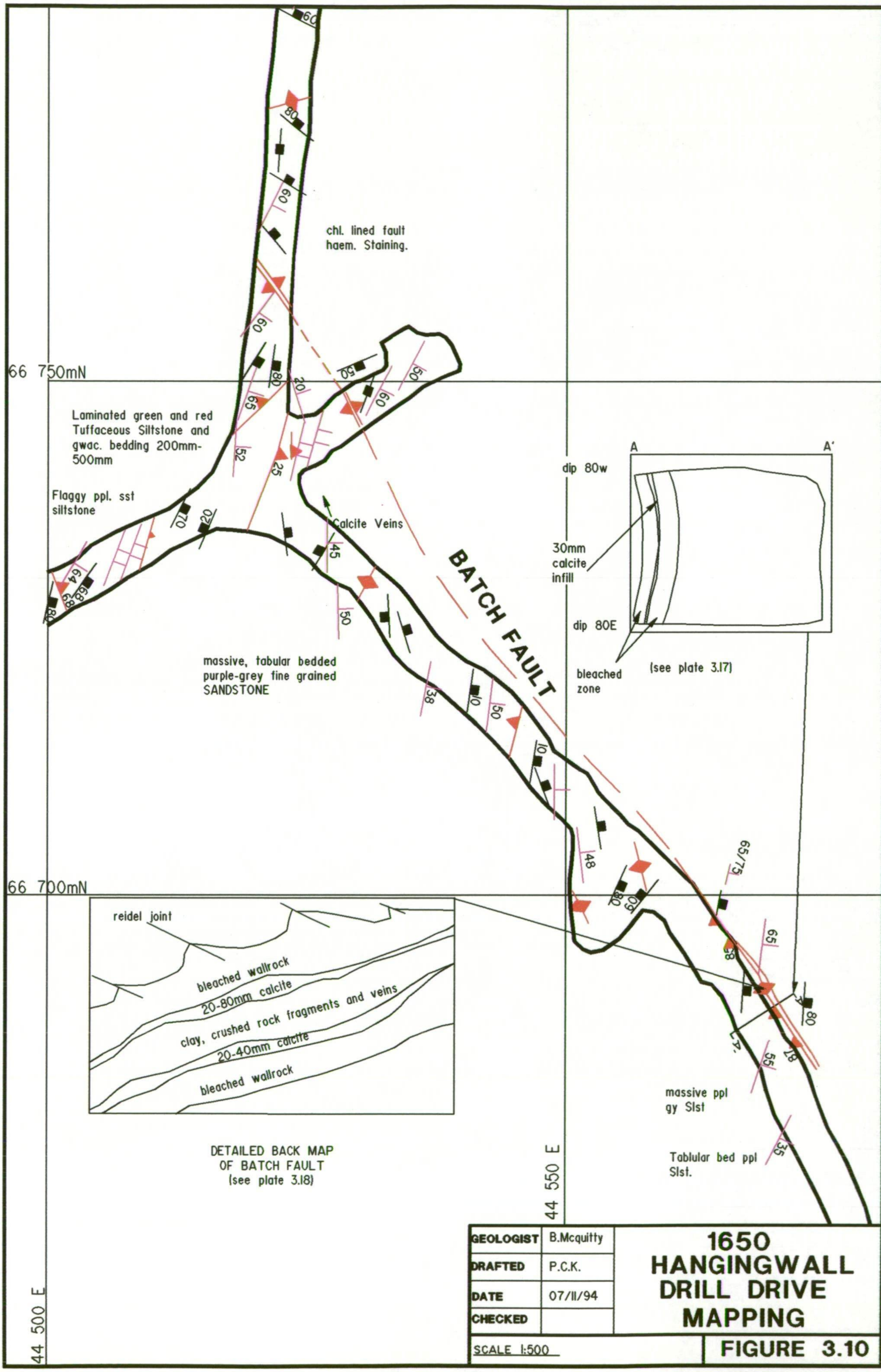
3.5.1.5 Batch Fault ...

The 1650 Crosscut, which accesses the 1650 Hangingwall Drill Drive through 250m of Crimson Creek Formation in the North Bassett Fault hangingwall intersected only one substantial fault in terms of displacement, mineral content and wallrock alteration. Mapping of this fault, the "Batch Fault", is presented in Figure 3.10. The fault is planar in strike (140° RMG) and curviplanar in dip (80° E to 80° W; Plate 3.17). It parallels Fault A and Fault Z.

In underground exposures the Batch Fault consists of single or double fractures up to 100mm wide and 500mm apart with infilling coarse carbonate and minor fluorite. Sparse disseminated pyrite occurs in a zone of bleached wallrock that extends for up to a metre either side of the structure. Well developed fault lineations are horizontal; detachment surfaces and jointing are locally developed in the Reidel R2 orientation (Fig. 3.9) indicating dextral strike slip movement has occurred (Plates 3.18 & 3.19). No evidence of dip slip history was observed.

The Batch Fault can be correlated in drillholes over a strike length of 200m and downdip for 250m. At depth, the structure hosts quartz-arsenopyrite-cassiterite veins overprinted by sulphide mineralisation.

An apparent throw of approximately 20m on the Batch Fault was determined by correlating subdivisions of the lower Crimson Creek Formation (Section 3.5.3). Given that the bedding locally dips 60° southeast, the horizontal displacement amounts to 10m. The fault occupies the axis of a syncline developed above the graben structure between Fault Z and the Csar Fault.


chl. lined fault
haem. Staining.
66 750mN
Laminated green and red Tuffaceous Siltstone and gwac. bedding 200mm-500mm
Flaggy ppl. sst siltstone
Calcite Veins
BATCH FAULT
massive, tabular bedded purple-grey fine grained SANDSTONE
A
A'
dip 80w
30mm calcite infill
dip 80E
bleached zone
(see plate 3.17)
66 700mN
reidel joint
bleached wallrock
20-80mm calcite
clay, crushed rock fragments and veins
20-40mm calcite
bleached wallrock
DETAILED BACK MAP
OF BATCH FAULT
(see plate 3.18)
massive ppl
gy Slst
Tablular bed ppl
Slst.
44 550 E
44 500 E
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1650
HANGINGWALL
DRILL DRIVE
MAPPING
FIGURE 3.10

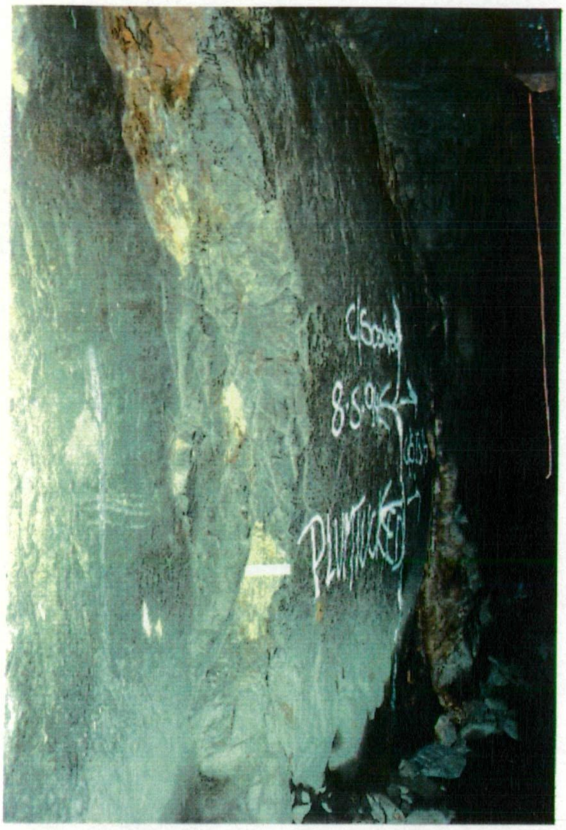

Plate 3.17 Exposure of Batch Fault in 1650 Hangingwall Drill Drive, looking south. Curved surface of the fault can clearly be seen. Scale rule is 15cm.

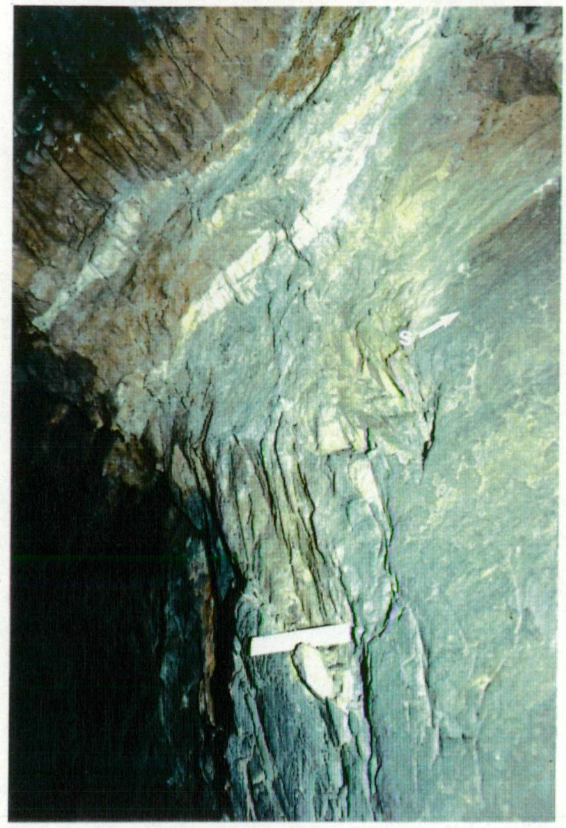

Plate 3.18 Exposure of Batch Fault in wall and backs of 1650 Hangingwall Drill Drive. Striations (s) indicate horizontal movement. Joints in foreground are in Riedel R2 orientation. A zone of bleaching occurs about the two major carbonate veins.

Plate 3.19 Oriented sample of carbonate vein from Batch Fault showing strongly developed grooves indicating horizontal strike slip movement.

3.5.1.6 Bedding-parallel Faulting ...

Faulting oriented sub-parallel to bedding was frequently observed during underground mapping of Romulus 1900 sill, Blackwood 1670 Sill access and the 1650 Hangingwall Drill Drive (localities shown in Figure 1.3). These are best developed in the laminated Renison Bell Member (Plate 3.20) or at the interface of dolomite horizons and ductile sulphide mineralisation with mor brittle units such as the Red Rock Member (Plates 3.21 & 3.22). The faults themselves are frequently mineralised, hence they formed pre- to syn-mineralisation.

The thinning of all stratigraphic horizons towards the North Bassett Fault, previously referred to in Section 3.5.1.1, can occur by: (1) bedding-parallel faulting, (2) reaction induced volume changes, or (3) ductile processes. Detailed logs of four drillhole intersections with the No. 2 Horizon on section 66700m N (Fig. 3.11) were carried out to investigate the processes responsible for the linear relationship between No. 2 Horizon thickness and distance from the North Bassett Fault (Fig. 3.6). Over a horizontal distance of 30 to 6 metres from the fault the true thickness reduced by 66% (Fig. 3.11). If the reduction in thickness of the dolomite was due to recrystallisation or pressure solution, an increase in the amount of recrystallisation or stylolites should be evident towards the fault. However, there was little change in the textures of the unmineralised dolomite between drillholes. Stylolites were sparse throughout and carbonate veins were evenly distributed, amounting to less than 10% by volume of the dolomite. Coarse siderite-magnetite crystals occurred in equal proportions in both U2395 and U1350, therefore the 50% thickness reduction

3.5.1.6 Bedding-parallel Faulting ...

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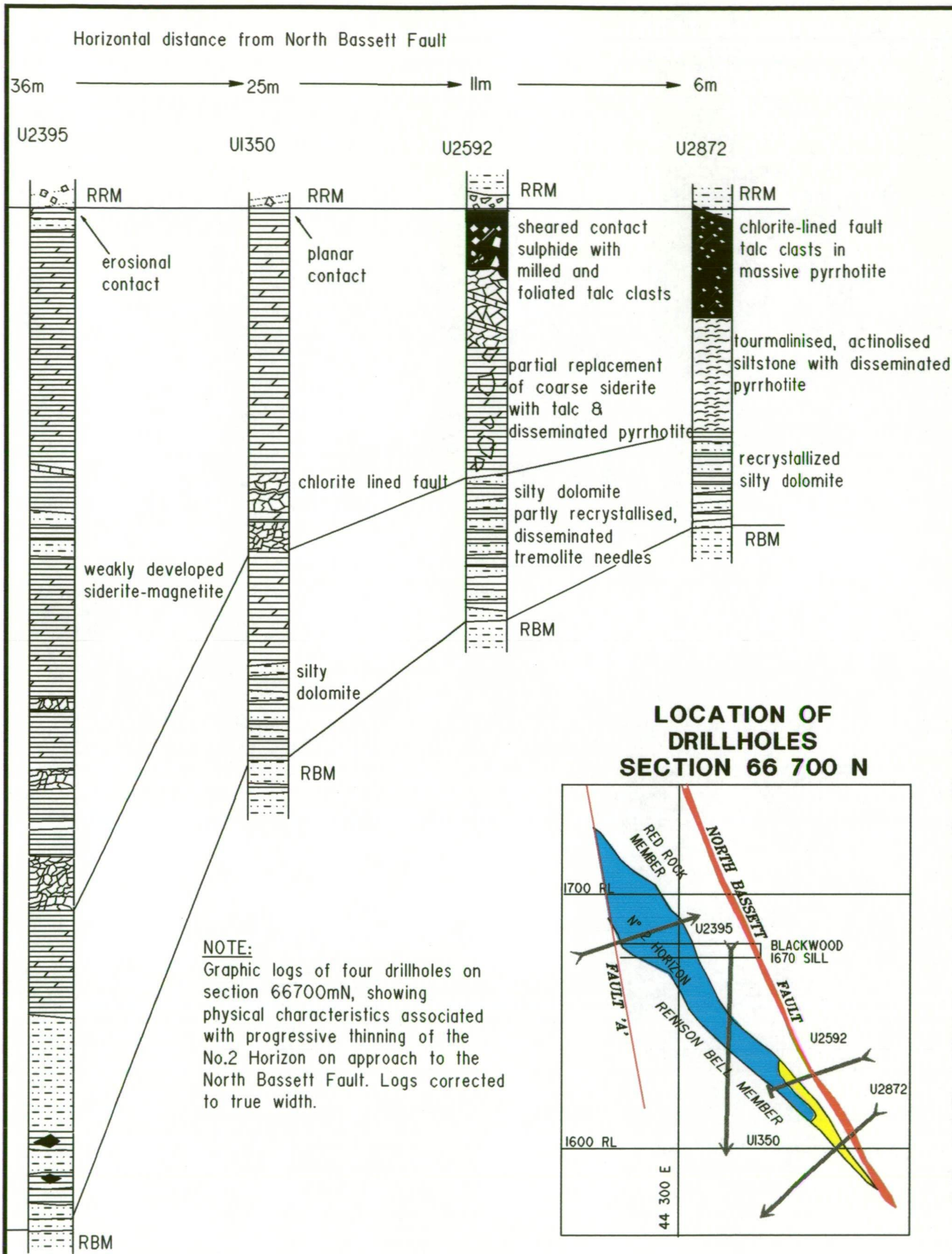
Plate 3.20 Romulus 1900 Sill face, 66850m N, north end. The Renison Bell Member (RBM), No. 2 Horizon (No.2) and Red Rock Member (RRM) are structurally thinned approaching the North Bassett Fault (NBF). Faults (F) sub-parallel to bedding (b), thought to be involved with the thinning process, are highlighted. The No. 2 Horizon is replaced by talc and pyrrhotite and has deformed in a ductile manner.

Plate 3.21 Exposure of No. 2 Horizon (No.2)/Red Rock Member (RRM) contact in 1650 Crosscut. The contact (yellow line) is faulted sub-parallel to bedding. A boudin-shaped sliver of partly mineralised dolomite (do) occurs at the contact.

Plate 3.22 Closeup of Plate 3.21, showing corestone of unmineralised dolomite, surrounded by alteration halo of coarsely crystalline siderite. Talcose sulphide mineralisation occurs only at the faulted margins, implying that faulting was pre- to syn-mineralisation.



DOLOMITE- all at least partly recrystallised, carbonate veins amounting to not more than 10% vol., sparse stylolites throughout.

SILTSTONE

COARSELY crystalline siderite with abundant magnetite

MASSIVE PYRRHOTITE

MAJOR CARBONATE VEIN

GEOLOGIST	B.McQuitty
DRAFTED	S.F.M.
DATE	8/12/94
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FAULT THINNING OF No.2 HORIZON

FIGURE 3.11

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between these two drillholes cannot be accounted for by strain or volume loss accompanying recrystallisation of the dolomite.

Between drillholes U1350 and U2592 there is development of a fault at the No. 2 Horizon hangingwall which was a site for mineralisation. Milled talc clasts were noted in a massive sulphide matrix in drillholes U2592 and U2872.

Faulting at the hangingwall is the most plausible process by which thinning of the No. 2 Horizon has occurred in the absence of evidence for other processes. Bedding parallel faults were sites for ingress of mineralising fluids both post- and syn-faulting. Volume loss during the replacement process and recrystallisation of dolomite to calc-silicate minerals may make minor contributions to the observed thinning.

Bedding-parallel faulting was noted by Holyland (1987) who regarded flexural slip as a major component of deformation in the "Bassett Monocline" and that uncoupling of bedding planes during folding created sites for hydrothermal fluid ingress. Flexural slip would be facilitated in the North Bassett Structure by the layered, high competency contrast of the Renison Mine Sequence compared to the more massive Dalcoath Member and Crimson Creek Formation (Chapter 2, Section 2.6).

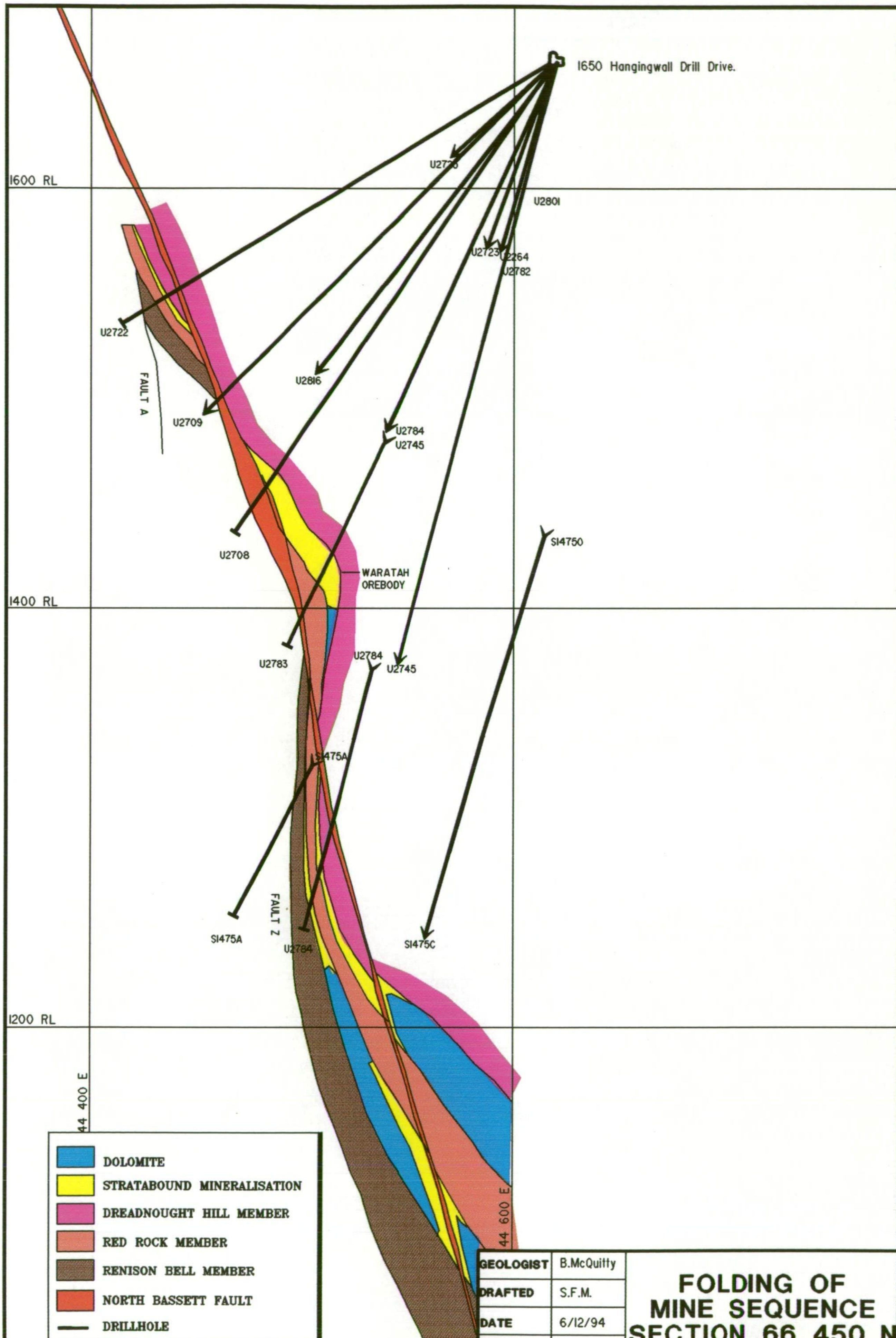
3.5.2 Ductile Deformation ...

3.5.2.1 D3 Drape Folds ...

The transition from predominantly brittle deformation to increasingly ductile deformation towards the Pine Hill Granite has been inferred previously in Sections 3.5.1.2 and 3.5.1.3. An open fold with Z asymmetry and westward vergence was interpreted to explain the presence of Renison Mine Sequence in the hangingwall of the North Bassett Fault above 1350m RL, south of section 66550m N, although the geometry is not well constrained by the current drilling. The profile of this fold, which has an axial plunge of 26° to the south, is shown in Figure 3.12. The fold is classified as a Type 3B with diverging dip isogons, according to the classification system developed by Ramsay (1967) and refined by Zagorcev (1993; Fig. 3.13). The Waratah orebody (No. 1 Horizon) is developed in the hinge region of the fold. The North Bassett Fault transects the folded Renison Mine Sequence at a low angle to the dip and strike of the bedding. A steep, west dipping fault was also considered in order to explain the offset of the Renison Mine Sequence across the North Bassett Fault. Drillholes examined for evidence of a fault in the Crimson Creek Formation above the Waratah orebody showed no evidence of major brittle structures that would account for this offset. This folding could be associated with one of two deformation events:

i) parasitic folding on the eastern limb of the Devonian D2 Renison Anticline.

ii) drape folding of the Renison Mine Sequence about the uplifted block of



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FOLDING OF MINE SEQUENCE SECTION 66 450 N

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FIGURE 3.12

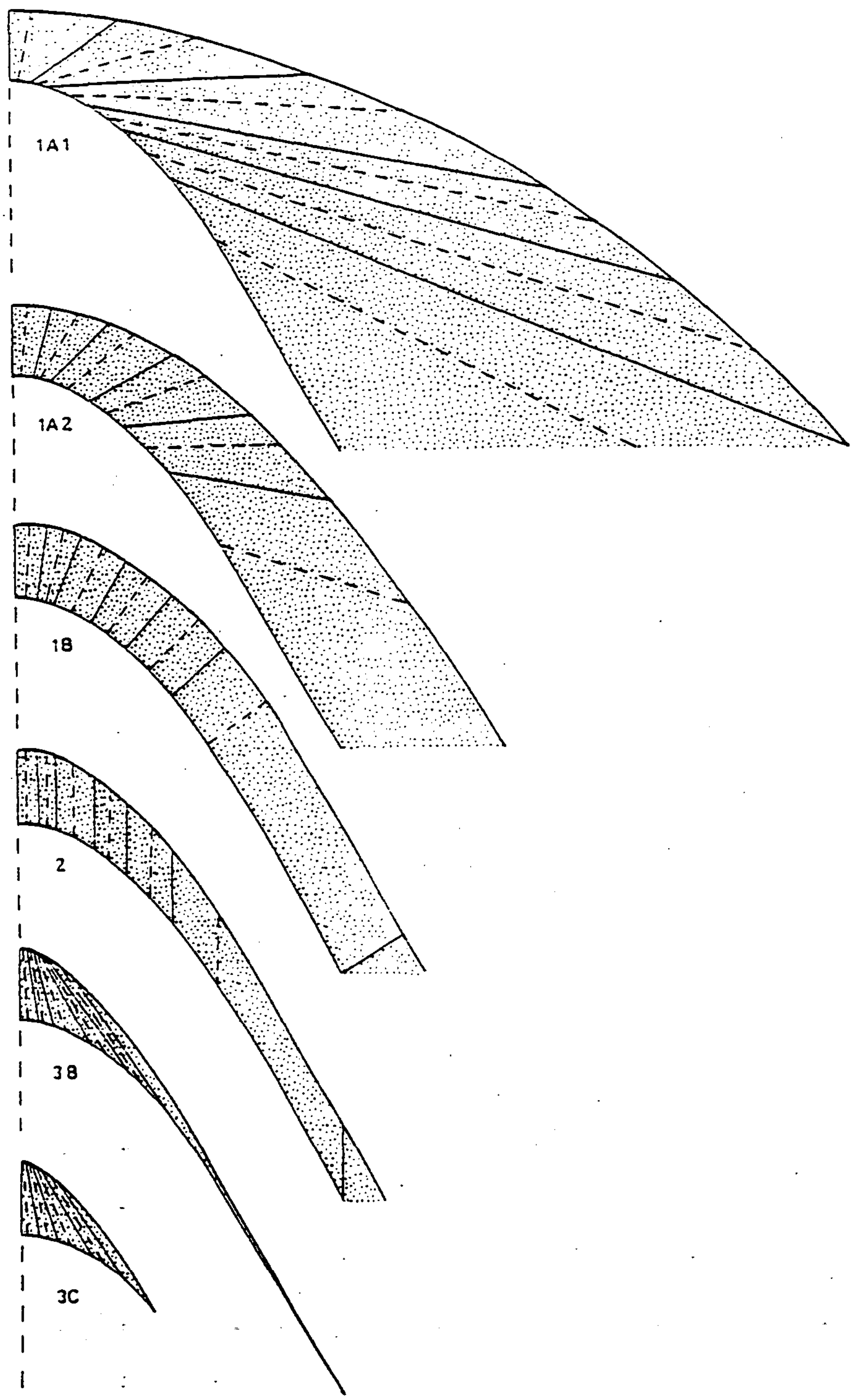


Figure 3.13 Profiles of different fold types developed above a sinusoidal single surface with a maximum dip angle of 60°. Folding of segments of the Renison Mine Sequence in the North Bassett Structure resembles Type 3B folds, which have strongly diverging dip isogons (c.f. Fig. 3.12). (After Zagorcev, 1983).

Dalcoath Member to the west of Fault Z (Fig. 3.12) in response to subvertical principle stresses during intrusion of the Pine Hill Granite (Devonian D3 dip slip deformation event of Kitto, 1994).

Lagarde et al., in a study of deformation styles in thermal aureoles surrounding granitic plutons in the western Morrocan Hercynian belt, noted development of open, gently-plunging asymmetric folds in the outer zones of the aureoles, verging towards the plutons. Strain intensity was shown to be zoned concentrically about the plutons, indicating that deformation was in response to the intrusion. By analogy with this example the observed folding in Rendeep is related to D3 deformation.

Holyland (1987) proposed a method of drape folding by which normal faults propagate through competent sequences but are unable to penetrate the layered sequences (i.e. Renison Mine Sequence) which form drape folds by layer-parallel extension. Class 3 folds form in incompetent layers that have to accomodate the shape of the buckled competent layers during folding of a multi-layer sequence (Zagorcev, 1993).

The drape folding process is thought to apply in this case, but is associated with high angle reverse faulting (Fault Z) rather than normal faulting. The transition from normal faulting in the upper mine to high angle reverse faulting in the southen part of the Rendeep area results from a shift in the principle stress direction from vertical toward a slightly more radial pattern over the northeastern shoulder of the Pine Hill Granite apophysis underneath the Renison mine (Fig. 3.8).

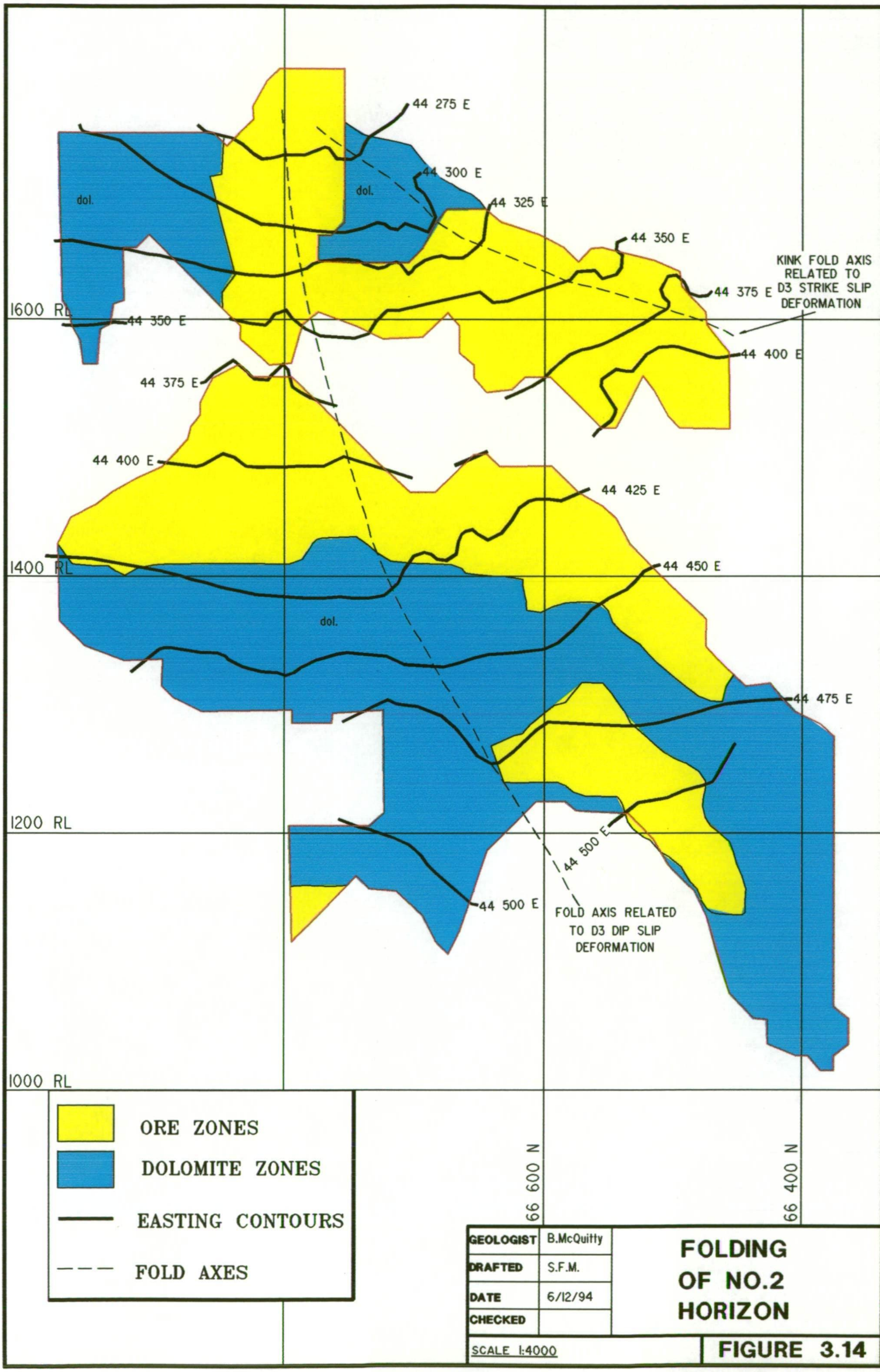
From their discordant relationship, the North Bassett Fault appears to postdate the drape fold developed about Fault Z. The North Bassett Fault is interpreted as having reactivated as a brittle structure after earlier syn-intrusion semi-ductile and flexural slip deformation. The lack of throw on the North Bassett Fault in this lower region of the North Bassett Structure is due to strain transferral onto Fault Z.

3.5.2.2 Concave-east Folding Related to D3 Dip-slip Deformation ...

The concave-east inflection in the North Bassett Fault north of 66400m N was described in Section 3.5.1.1 (Fig. 3.4). The strike of the Renison Mine Sequence parallels that of the North Bassett Fault, displaying a broad, gentle open concave-east fold (Fig. 3.4). Footwall easting contours were constructed for the No. 2 Horizon to locate the fold axis and these are presented in longitudinal projection in Figure 3.14. The fold axis plunges 75° to the south above 1400m RL, flattening to 60° to the south below 1400m RL. Kitto (1994) noted a similar plunge and trend of 70° to 202° for the sigmoidal jog observed on the Federal-Bassett Fault between "Shear P" and "Shear L" which he associated with normal-dextral movement on the fault plane (Devonian D3 dip-slip event). The concave-east fold is thought to have originated through transferral of normal-dextral movement from the North Bassett Fault onto Faults A and Z during Devonian D3 dip-slip deformation.

3.5.2.3 Folding Related to D3 Strike-slip Deformation ...

The plot of easting contours to the No.2 Horizon, Figure 3.14, reveals the presence of



FOLDING OF NO.2 HORIZON

FIGURE 3.14

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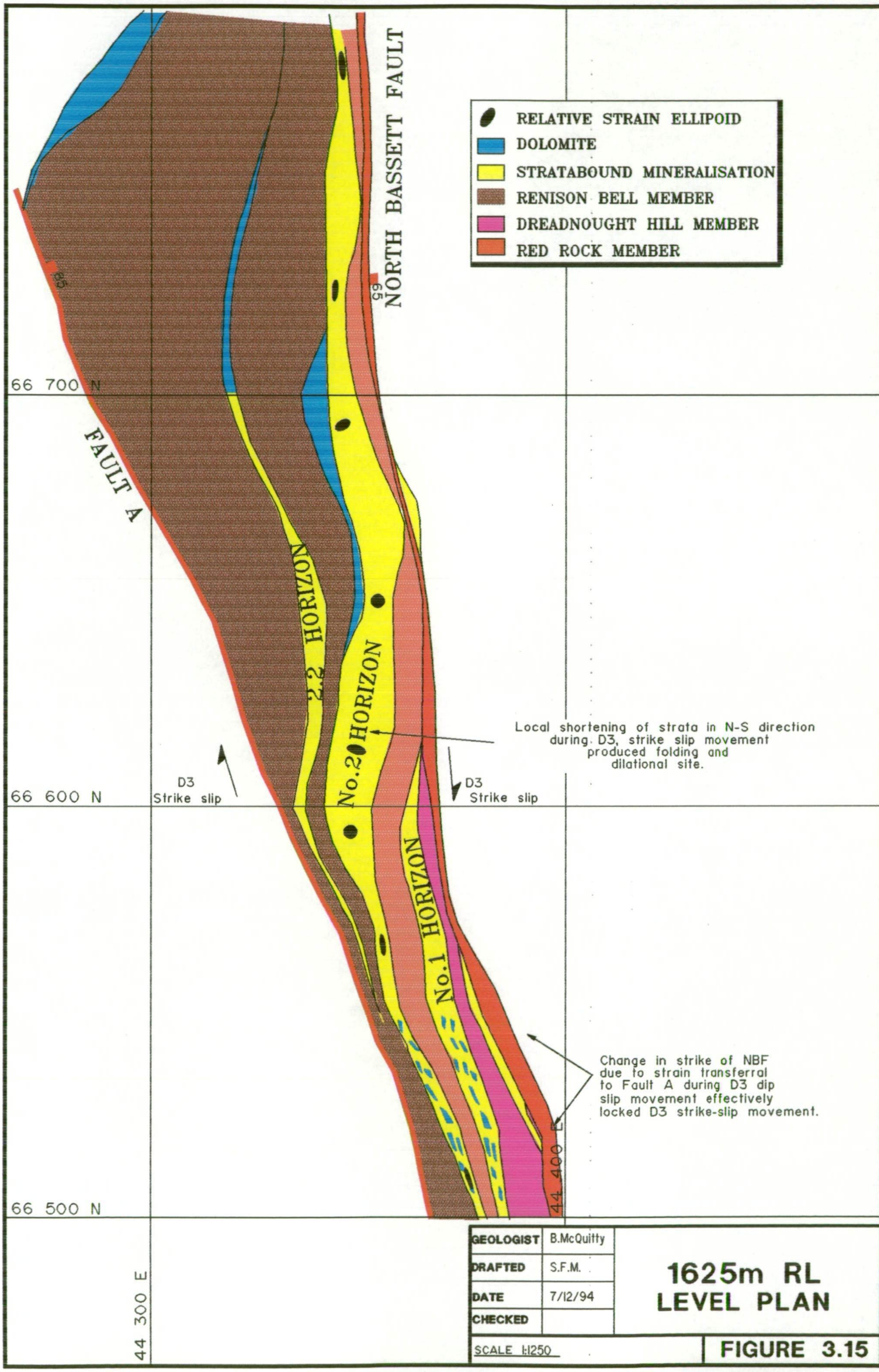
another, shorter wavelength fold axis. The fold axis plunges south at 20° and occurs close to the projected contact of Fault A with the North Bassett Fault. Figure 3.15, a plan view of the interpreted geology at 1625m RL, shows that the fold is a weak dextral kink fold which displays local thickening of strata on the short limb.

Weak dextral kink folding was recognised on the Renison Horst Kitto (1994) and in the steeply dipping Renison Mine Sequence close to the Federal-Bassett Fault (Marjoribanks, 1989) and was considered by Kitto (op cit.) to be associated with Devonian D3 strike-slip deformation and the main stage of mineralisation (Section 3.2.5). Similar kink folds occur in the No. 2 Horizon in the Romulus 1900 sill in the North Bassett area (Fig. 3.16; location: Fig. 1.3) and in the North Stebbins 1860 sill in the Federal area (Fig. 3.17; location: Fig. 1.3).

The kink folding in Figures 3.15 and 3.16 occurs at the point at which the separation between Fault A and the North Bassett Fault closes to 50m. The folds are thought to form from local north-south shortening in response to locking of D3 dextral strike-slip movement on Fault A and the North Bassett Fault by the strike inflection on North Bassett Fault created during D3 dip-slip movement.

A shallow-dipping reverse fault with lineations plunging 15° south was mapped in the Blackwood 1670 sill access (Fig. 2.3, right wall). This fault was associated with carbonate-magnetite and chlorite mineralisation. Faults of this orientation are predicted by models of wrench tectonics (Fig. 3.9) and form in response to north-south shortening.



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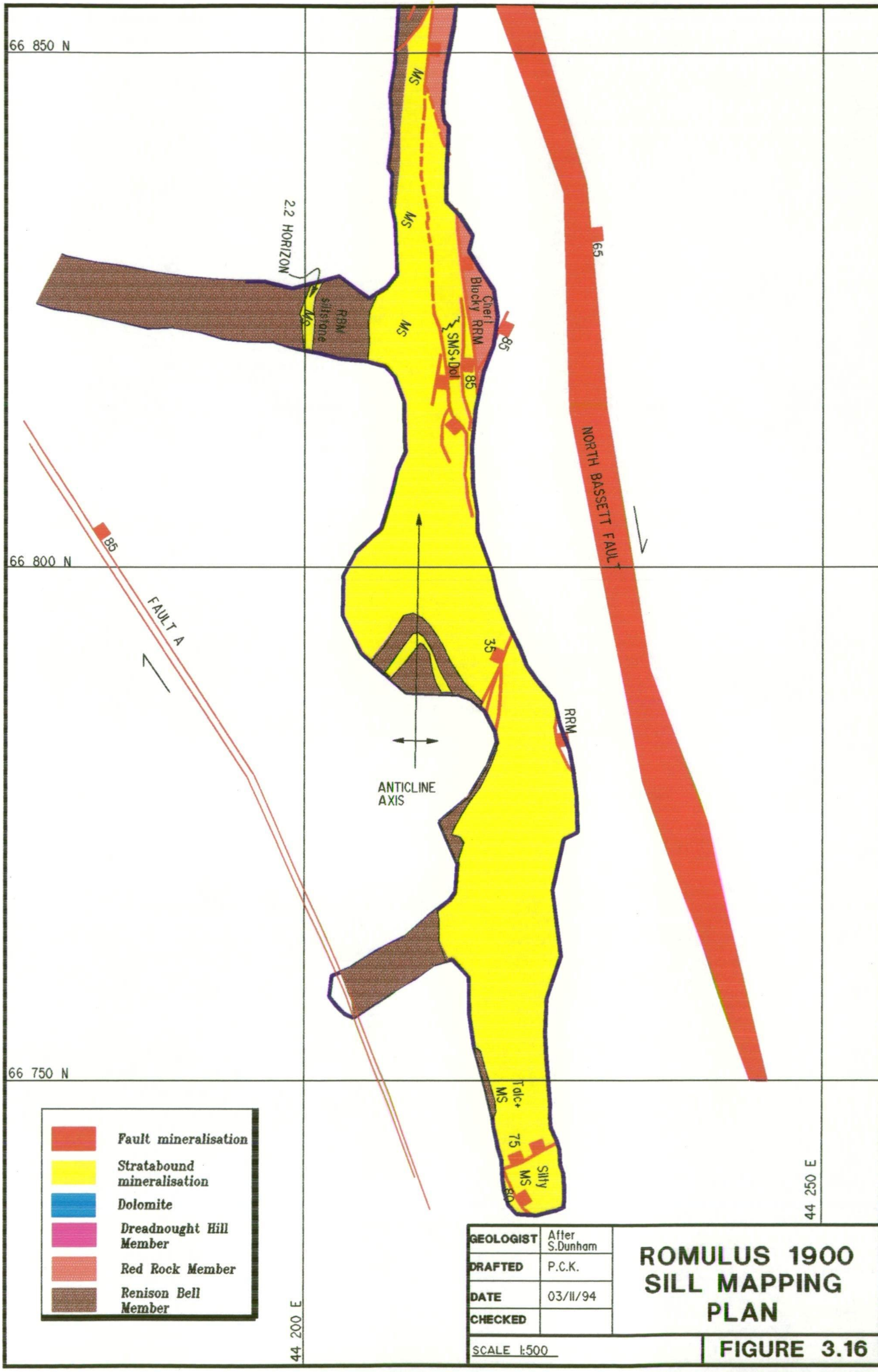

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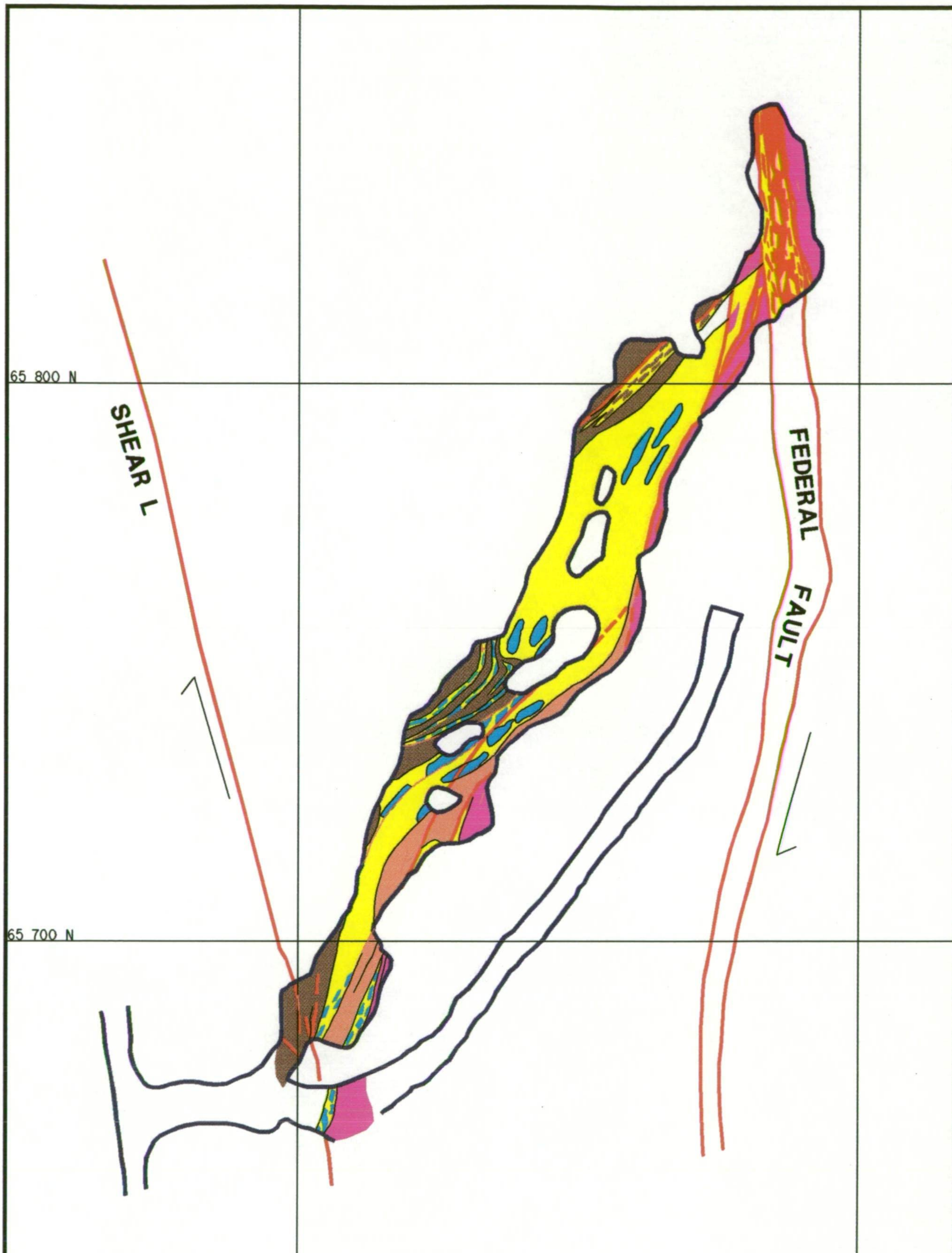

LEGEND

Fault mineralisation	Renison Bell Member
Stratabound mineralisation	Redrock Member
Dolomite	Dreadnought Hill Member

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SCALE 1:1000		**FIGURE 3.17**

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3.5.2.4 Reaction-Induced Deformation ...

The products of replacement reactions at Renison, such as pyrrhotite, chlorite and talc have considerably lower strength and greater ductility than the rocks they replace (Chapter 2, Section 2.6). Evidence such as milled talc clasts in a pyrrhotite matrix (Fig. 3.11) suggest the faults were open and moving during mineralisation. Plate 3.23 shows the progressive ductile deformation of replacement minerals talc and pyrrhotite away from the reaction front with relatively brittle dolomite. The replacement reactions have been facilitated by frequent fault reactivations allowing further hydrothermal fluids access to the reaction front (Patterson, 1979). Fault movements were facilitated, in turn, by the weaker rocks produced by replacement reactions.

Holyland (1987) undertook a correlation of dolomite horizon thickness and degree of replacement on three upper mine orebodies and found a positive linear relationship. He concluded that reaction induced thinning involving volume loss was the dominant process in accounting for thickness variations in the dolomite horizons. Ductile deformation of the reaction products, however, rather than reaction induced volume changes may account for this relationship.

3.5.2.5 Ductile Processes at the Microscopic Scale ...

Twenty-six thin sections were examined to determine the extent of strain flattening developed in the North Bassett Structure. Most samples were collected from Faults

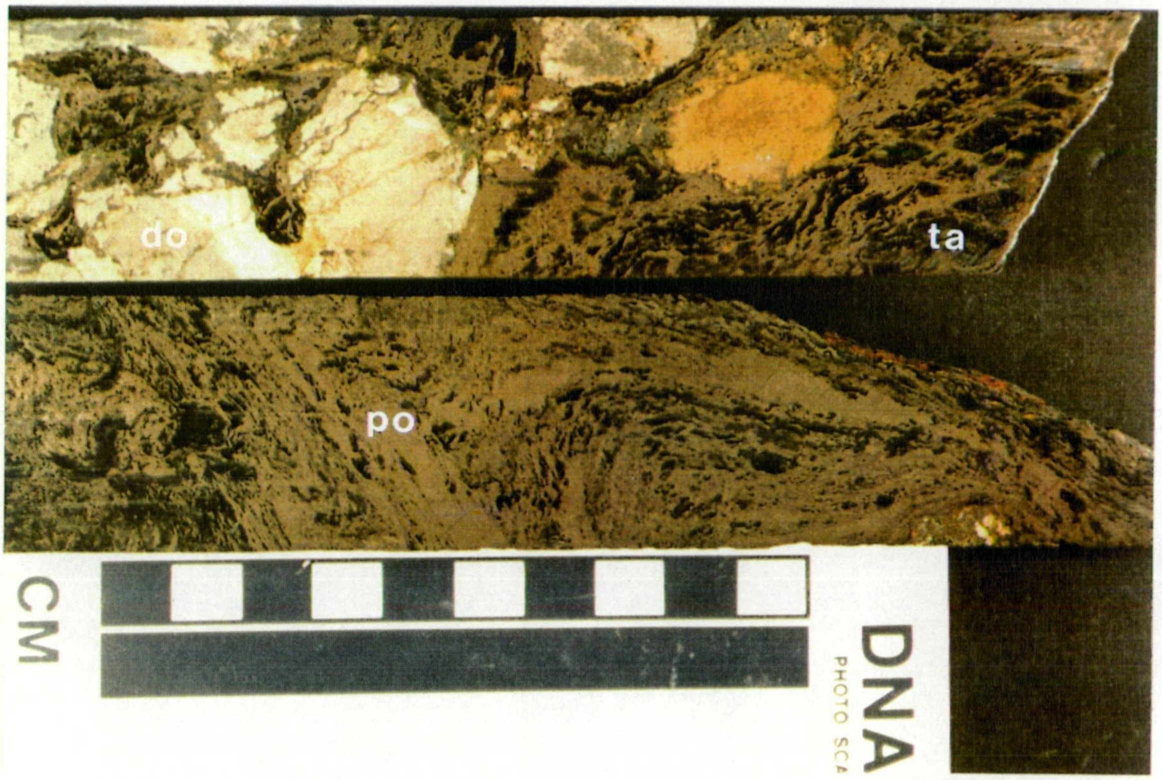


Plate 3.23 Reaction front, drillhole U2347, 126.4m and 127.3m. Dolomite (do) undergoing replacement. Reaction products, talc (ta) and pyrrhotite (po) deform readily in a ductile manner.

A and Z. Some samples were collected from drillcore remote to major faults. Plates 3.24, 3.25, 3.26 and 3.27 present a comparison of deformational textures between the highly deformed, well-bedded Renison Bell Member(?) sandstone and shale from Fault Z and the massively-bedded Crimson Creek Formation diamictite in drillhole U2592, located 50 metres into the hangingwall of the North Bassett Fault. Infilling carbon defines a weakly developed cleavage in the poorly-sorted diamictite in U2592 (Plate 3.24). A well developed cleavage and schistosity is evident in the fine-grained meta-pelite from Fault Z. A small amount of tourmaline has formed in a pressure shadow behind an actinolised clast in the diamictite in drillhole U2592 (Plate 3.26). A well developed pressure shadow, filled with carbon has formed behind a sandstone clast in drillhole U2736 (Plate 3.27). The presence of tourmaline in the pressure shadow in Figure 3.26 indicates that deformation was accompanied by boron metasomatism.

Insufficient flattening strain is observed to account for the thinning of strata in the North Bassett Structure by purely ductile deformation. Bedding-parallel faulting is considered to be the main mechanism by which this is achieved. The contrast in the amount of strain shown by the samples from the two drillholes is due to the respective rheology of the host rocks. Fault Z has developed as a high strain zone because the well-bedded carbonaceous shale horizons of the upper Dalcoath Member and middle Renison Bell Member readily undergo extension parallel to bedding once the bedding has been rotated parallel to the principle stress direction. The massively-bedded and homogeneous Crimson Creek Formation is more strain-resistant.

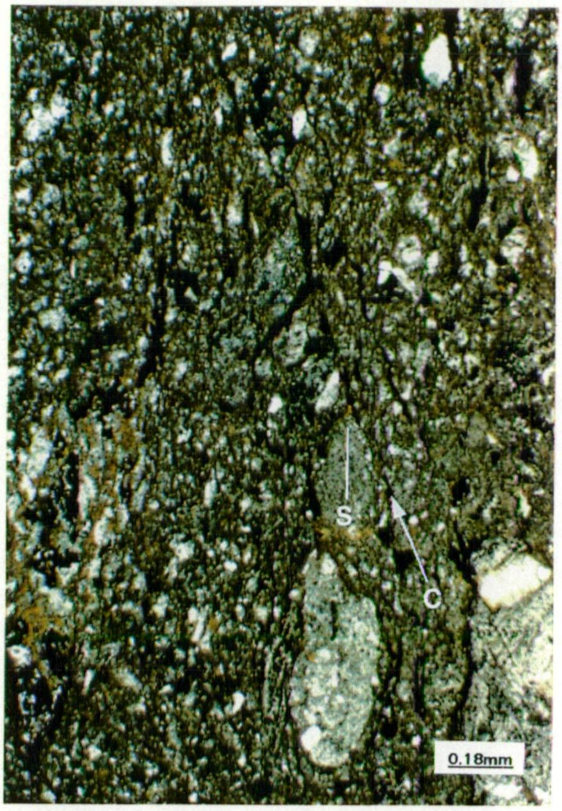


Plate 3.24 Weakly developed C and S fabric in diamictite, Limestone A?, Crimson Creek Formation. Drillhole U2592, 53.1m, plane polarised light.

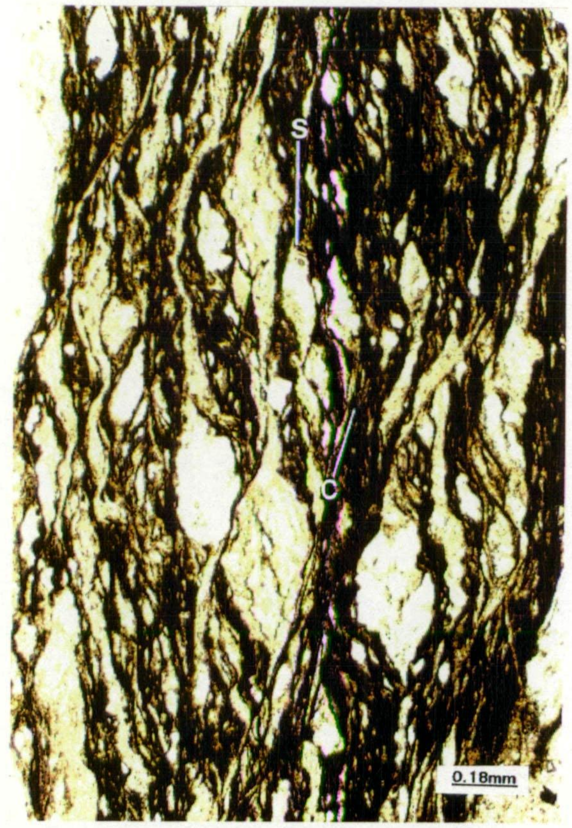


Plate 3.25 Well developed C and S fabric in shale and sandstone of Renison Bell Member?, Fault Z shear zone. Drillhole U2736, 299.8m. plane polarised light.

Plate 3.26 Tourmaline (to) formed in pressure shadow behind actinolised (ac) clast. Drillhole U2529, 53.1m. PPL.

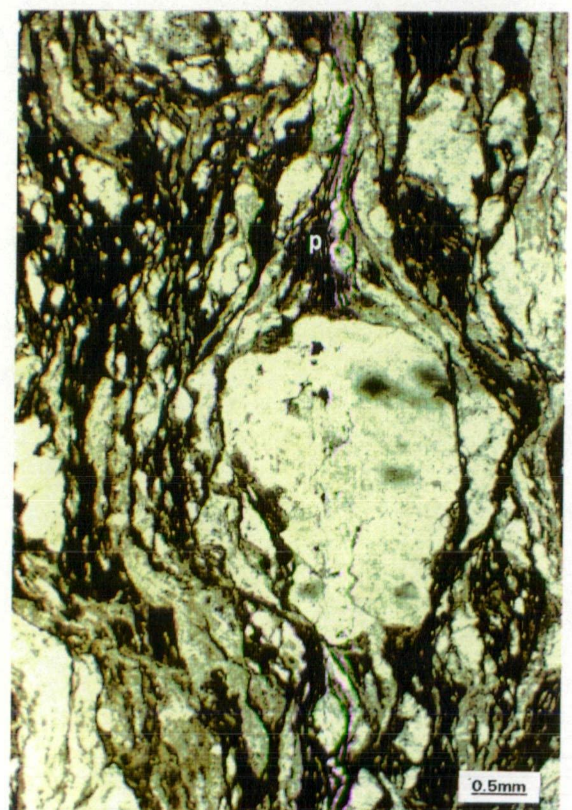


Plate 3.27 Carbon-filled pressure shadow (p) behind sandstone clast. Drillhole U2736, 299.8m. PPL.

3.5.3 Relationship of Crimson Creek Formation to North Bassett Structure

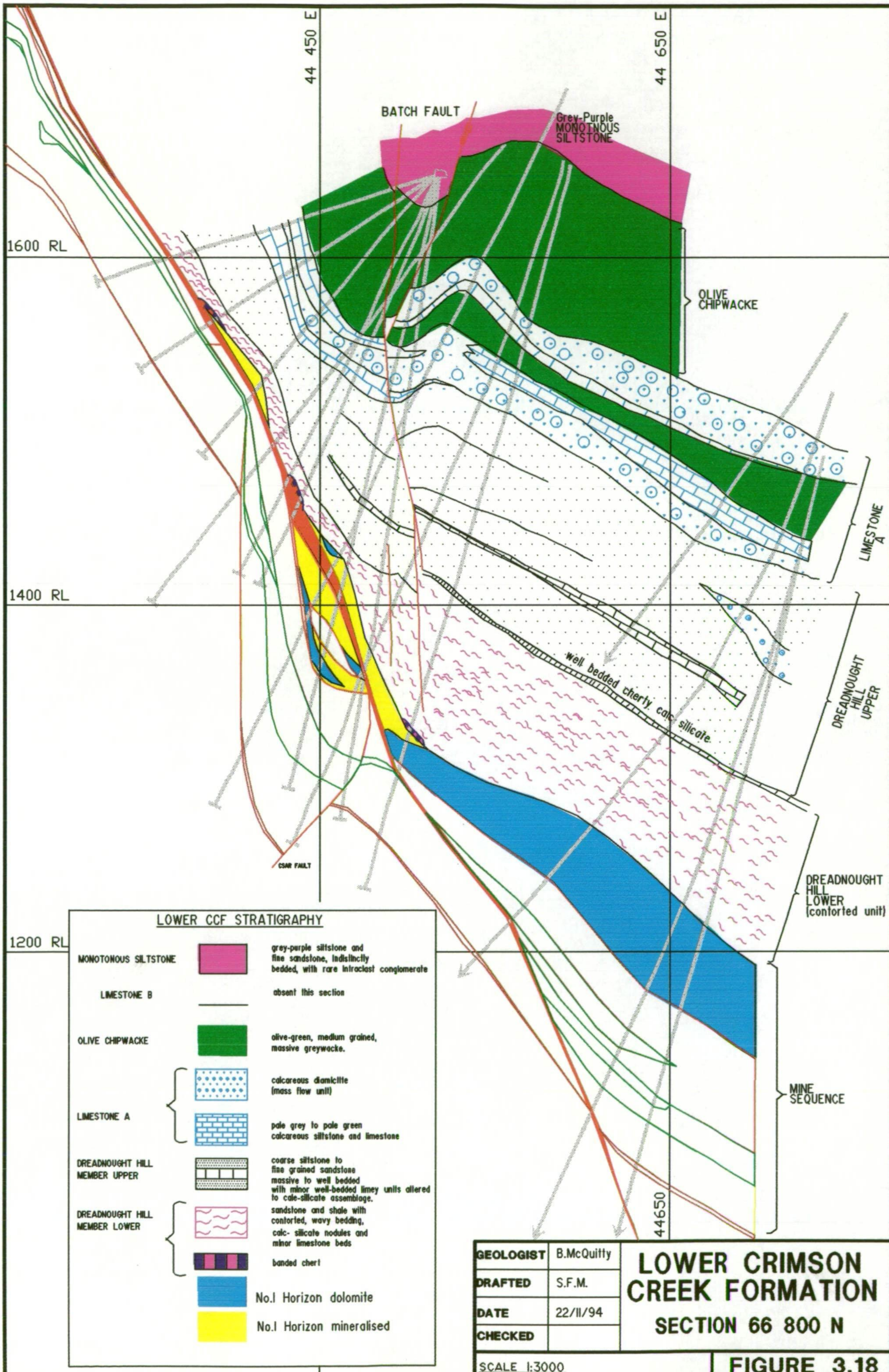
The preliminary stratigraphic subdivision for the lower 900m of the Crimson Creek Formation, developed by Morrison (1993; Chapter 2, Section 2.4) was used to resolve the structure above the Rendeep orebodies.

3.5.3.1 Correlation of units ...

The closely spaced fans of drillholes from the 1650 Hangingwall Drill Drive provided a unique opportunity to attempt a correlation of units of the lower 300m of the Crimson Creek Formation. Correlation was carried out by assigning geological descriptions of lithotypes from standard Renison geological logs to each of Morrison's (1993) major subdivisions. Mapping from the 1650 Hangingwall Drill Drive was also used. Correlation of individual lithologies proved difficult, even at the relatively close drillhole spacing. The effects of metasomatism masked the original sedimentary texture within 70m of the North Bassett Fault.

3.5.3.2 Structural interpretation ...

Results of the correlations are presented for the best-drilled cross-section, 66800m N (Fig. 3.18). The Lower Crimson Creek Formation conformably overlies the No. 1 Horizon and drapes the North Bassett Fault. This confirms the monoclinal nature of the North Bassett Structure. A small syncline is developed in the Lower Crimson Creek Formation, above the Rendeep Graben/Syncline. The Batch Fault occurs in the



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axis of the syncline. These structures are thought to have developed to accommodate the steepening dip of the Lower Crimson Creek Formation as it is draped up the North Bassett Fault. Most units maintain a relatively constant orthogonal thickness; the thinning of the formations on approach to the North Bassett Fault is due in part to an apparent effect created by rotation of the south-easterly (RMG) dipping beds into parallelism with the North Bassett Fault. However, similar strain-producing processes noted for the Renison Mine Sequence must also contribute to the observed thinning.

3.6 STRUCTURAL HISTORY ...

3.6.2 Devonian D2 Deformation ...

No unequivocal evidence for Devonian D2 deformation could be located in the Rendeep area, due to the strong overprint of Devonian D3 deformation and the broad, regional scale of such deformation. The southeasterly (RMG) dip of approximately 30° of the Renison Mine Sequence in the North Bassett Structure hangingwall may be a product of D2 or earlier D1 deformation. The most important aspect of regional D2 deformation was the creation of the Renison Bell Anticline into which the Pine Hill Granite intruded (Kitto, 1994).

3.6.3 Devonian D3 Dip-slip Deformation ...

Intrusion of the Pine Hill Granite by forceful means produced 770 m of vertical displacement of the Renison Mine Sequence in the North Bassett area (Fig. 3.2). In the North Bassett Structure deformation occurred initially by ductile means but as bedding was rotated from 30° and 60° bedding-parallel faulting and subvertical brittle faulting became the dominant deformation processes. Faults A and Z formed as dip slip faults in response to a sub-vertical principle stress direction (Fig. 3.8). The deformational fabric in these structures displays a transition from brittle to ductile, corresponding to temperature zonation around the Pine Hill Granite and indicates a syn-intrusive timing. Early ductile deformation accompanied boron metasomatism (Plates 3.10 & 3.26).

In the Rendeep area, Fault Z formed by bedding-plane slip in well-bedded horizons as the Renison Mine Sequence was folded into near-parallelism with the principle stress direction. North of 66750m N, the Rendeep Graben/Syncline structure formed as a result of this folding and normal movement on the Csar Fault (Fig. 3.2). Drape folding of the Renison Mine Sequence about Fault Z occurred in the southern part of the Rendeep area (Fig. 3.12).

The North Bassett Fault formed synchronously with Faults A and Z through failure of the Renison Mine Sequence by interstratal slip. The failure plane corresponds to the contact of the No. 1 Horizon with the overlying Dreadnought Hill Member over much of the North Bassett Structure. Strain was transferred from the North Bassett Fault to Fault Z below their projected contact. A concave-east inflection in the North Bassett Fault, plunging at 70° to the south, formed north of 66400m N during D3 dip-slip deformation.

In the Deep Federal area (Fig. 1.3) 75 to 100m throw on the mineralised Federal-Bassett Fault is indicated by displacement of the Pine Hill Granite surface (Section 3.4.1). In the same area, the throw on the Federal-Bassett Fault, as indicated by the displacement of the Renison Mine Sequence, is over 1000 m (Patterson, 1979). This apparent discrepancy is explained as the majority of displacement on the Federal-Bassett Fault occurring as semi-ductile deformation and interstratal slip during granite intrusion at solidus temperatures <650°C (Bajwah *et al.*, in press). Subsequent cooling and crystallisation of the outer shell of the granite, while diapiric uplift was still in progress allowed the Federal-Bassett Fault to continue to develop as a dip-slip brittle fault, penetrating the granite surface, producing 75 to 100m of displacement and facilitating the release of volatiles. Alternatively, expansion of the crystalline carapace due to the pressure created by volatile buildup in the underlying magma, produced dip-slip reactivation of the Federal-Bassett Fault (Kitto, 1994). By either process, the first significant mineralisation is interpreted as occurring late in the Devonian D3 dip-slip deformation event.

3.6.4 Devonian D3 Strike-Slip Deformation ...

In the Rendeep area, D3 strike-slip deformation reactivated Fault A, Fault Z (?) and the North Bassett Fault and created or reactivated the Batch Fault (for which no evidence of previous dip-slip history was observed). Strike-slip movement on the North Bassett Fault was restricted by the concave-east inflection created by D3 dip-slip deformation and strain was transferred onto the parallel structures; Fault A and Batch Fault. North-south shortening of the Renison Mine Sequence produced a weak dextral kink fold with an axial plunge of 20° to the south, between Fault A and the North Bassett Fault above 1600m RL (Figs. 3.14 & 3.15). A reverse fault mapped in the Blackwood 1670 sill access (Fig. 2.3), with similar plunge and trend of lineations (15° south) also formed in response to north-south shortening.

3.6.5 Post-Devonian Deformation ...

Post-Devonian brittle reactivations in the Rendeep area were not studied in detail because they post-date mineralisation. The minor displacements associated with these reactivation events cannot be correlated between drillholes in the Rendeep area. Post-Devonian reactivations are responsible for unmineralised fault breccia frequently observed in the immediate hangingwall of the North Bassett Fault.

3.7 SUMMARY ...

The structural preparation of the Rendeep area is dominated by Devonian D3 deformation events associated with the development and decay of the local stress field created by the intrusion of the Pine Hill Granite into the Devonian D2 Renison Anticline (Kitto, 1994). D3 dip-slip deformation produced 770m of throw on the North Bassett Structure, a failed monoclinal fold, by a combination of brittle and ductile deformation processes, with ductile processes dominant closer to the Pine Hill Granite. Folding and flexural slip resulted in unlocking of bedding planes in the strongly layered Renison Mine Sequence, creating potential sites for fluid ingress. A major dilational site, the Rendeep Graben/Syncline, was created below 1450m RL, north of 66750m N by rotation of the dip of the Renison Mine Sequence from 30° in the North Bassett Fault hangingwall to vertical and draped along Fault Z (Fig. 3.2). The Csar Fault assisted in creating this structure.

A broad, open, concave-east fold formed in the Mine Sequence and the North Bassett Fault north of 66400m N during D3 dip-slip deformation with an axial plane plunging in the inferred slip direction.

Faulting of the crystallised outer shell of the cooling Pine Hill Granite under the Federal area by the Federal Bassett Fault occurred late in the Devonian D3 dip-slip deformation event, releasing the first stage of mineralising fluids.

D3 strike-slip deformation produced brittle reactivations of Faults A, Z(?), the North Bassett Fault and initiated(?) the Batch Fault. The concave-east fold formed during D3 dip slip deformation and effectively locked D3 strike-slip movement above 1600m RL, resulting in local north-south shortening. This event created a weak dextral kink fold with a shallow south-plunging axis and resulted in a dilational site.

The following chapter seeks to model the hydrothermal fluid flow and explain the observed patterns in terms of the structural processes outlined above.

CHAPTER 4: MINERALISATION

4.1 INTRODUCTION ...

A number of dilational structures in the Rendeep area were proposed in Chapter 3. In this chapter the spatial relationship between these structures and the migratory pattern of mineralising hydrothermal fluids is explored. The interpretations are supported by the following lines of evidence:

1) modelling of the tin grade distribution,
2) oxygen isotopes,
3) sulphur isotopes, and
4) homogenisation temperatures from primary fluid inclusions.

Stable isotope and fluid inclusion studies have been used at Renison by previous workers, including Patterson (1979), Davies (1985) and Holyland (1987), prior to an extensive study by Kitto (1994). It is neccessary to constrain sampling by recognition of mineral paragenesis because Renison had a particularly long-lived hydrothermal system and spatial variations in the pattern of hydrothermal flow have occurred with time (Kitto, *op. cit.*).

This chapter commences with a review of the mineral paragenesis of the Renison deposit, before presenting the results from modelling of the hydrothermal fluid flow. The significance of the results are discussed in terms of structural controls on mineralisation and the brittle-ductile transition is briefly examined in terms of the temporal and spatial distribution of mineralisation.

4.2 MINERAL PARAGENESIS ...

4.2.1 Previous Work ...

Kitto (1994) developed a vein paragenesis for the Renison deposit with 5 main mineralogical stages that represent temporal variations in the mineralogy of the deposit with decreasing temperatures (Fig. 4.1). Each mineralogical stage is separated by distinct deformation events, previously outlined in Section 3.2. The mineralogical stages are:

1) Oxide-silicate Stage
2) Sulphide Stage
3) Late Base Metal Stage
4) Vug-fill Carbonate Stage
5) Supergene Stage

Kitto (1994) considered the earliest mineral assemblages of the Oxide-silicate Stage to be contemporaneous with normal-dextral movement on the Federal-Bassett Fault. Later

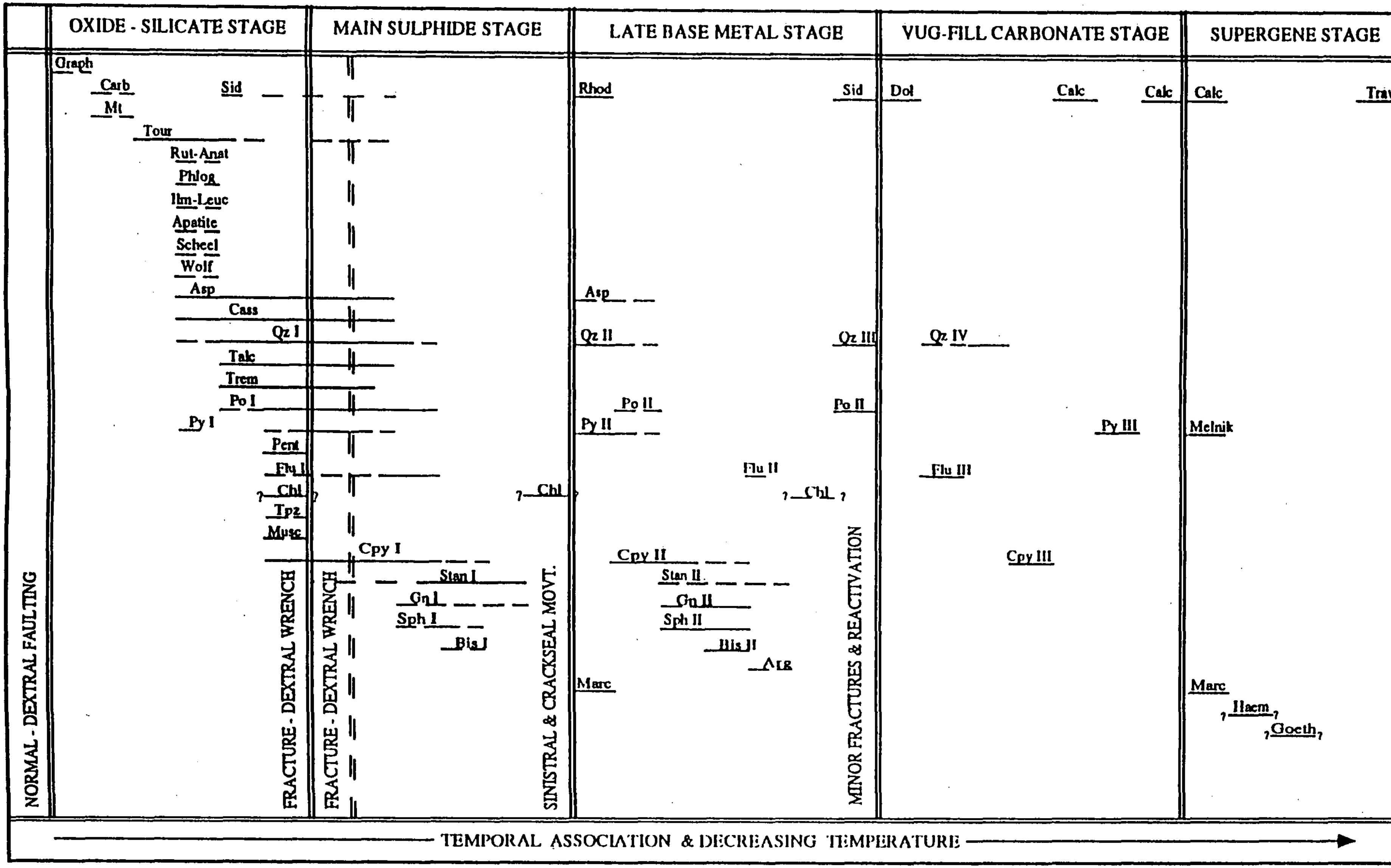


Figure 4.1 Mineralogy, vein paragenesis and deformation relationships for the Renison Tin Mine, western Tasmania. Abbreviations: Anat - anatase; Arg - argentite; Asp - arsenopyrite; Bis - bismuth; Calc - calcite; Carb - carbonate; Cass - cassiterite; Chl - chlorite; Cpy - chalcopyrite; Dol - dolomite; Flu - fluorite; Gal - galena; Goeth - goethite; Graph - graphite; Haem - haematite; Ilm - ilmenite; Leuc - leucoxene; Marc - marcasite; Melnik - melnikovite; Mt - magnetite; Musc - muscovite; Pent - pentlandite; Phlog - phlogopite; Po - pyrrhotite; Py - pyrite; Qz - quartz; Rut - rutile; Scheel - scheelite; Sid - siderite; Sph - sphalerite; Stan - stannite; Trav - travertine; Wolf - wolframite (from Kitto, 1994).

Oxide-silicate Stage mineral assemblages commenced prior to the onset of dextral strike-slip reactivation and were firstly quartz-, then sulphide-dominant. Main Sulphide Stage mineralisation accompanied, and immediately preceeded, dextral wrench reactivation of major faults and produced the widespread, pyrrhotite-dominated stratabound carbonate replacement mineralisation at Renison (Kitto, *op. cit.*). Cassiterite, the only tin ore mineral recovered at Renison, occurs in both the Oxide-silicate and Main Sulphide Stages.

Late Base Metal Stage mineralisation is tenuously linked with reverse-sinistral reactivation on major faults by Kitto (1994). The Vug-fill Carbonate Stage infills brecciated sedimentary rocks and earlier stages of mineralisation. Neither of these stages are of economic significance apart from their diluting effect upon previous cassiterite-bearing stages of mineralisation.

4.2.2 Examples from Rendeep Area ...

Plates 4.1, 4.2 and 4.3 show examples of mineral paragenetic relationships from the Rendeep area. Plates 4.1 and 4.2 are examples of Main Sulphide Stage mineralisation overprinting an Oxide-silicate Stage assemblage. The milled carbonate-magnetite clasts in Plate 4.1 and the veining and possible milling of the cassiterite aggregate in Plate 4.2 are evidence of deformation occurring between the two stages. Plate 4.3 is an example of Vug-fill stage carbonate-quartz mineralisation infilling brecciated pyrrhotite of the Main Sulphide Stage.

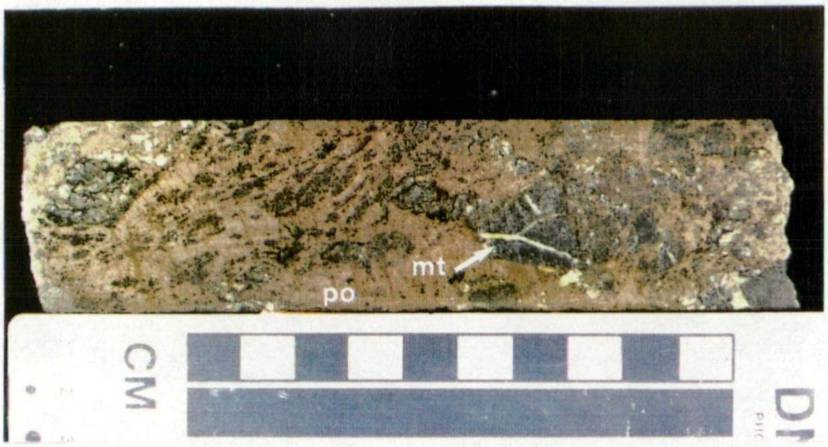


Plate 4.1 Milled clasts of carbonate-magnetite (mt), oxide-silicate stage (Stage 1), incorporated in pyrrhotite (po), main sulphide stage (Stage 2). Drillhole U2347, 124.1m.

Plate 4.2 Rounded (milled?) aggregate of cassiterite (ct) (Stage 1), incorporated in pyrrhotite (po) (Stage 2) which is deformed around, and forms veins in, the cassiterite. Drillhole U2748, 428m.

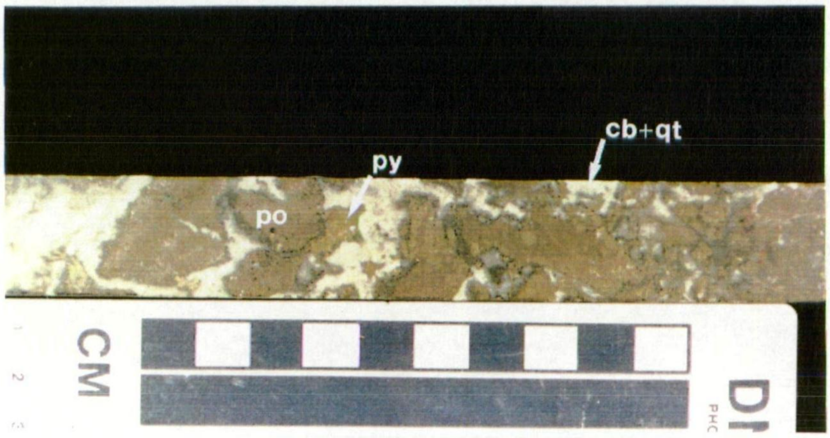


Plate 4.3 Carbonate-quartz (cb + qt), vug-fill carbonate stage (Stage 4), infilling brecciated pyrrhotite (po), producing reversion of pyrrhotite to pyrite (py). Drillhole U2515, 243m.

The Rendeep area exhibits the same mineral paragenesis as the rest of the Renison deposit.

4.3 MODELLING OF TIN GRADE DISTRIBUTION ...

4.3.1 Method ...

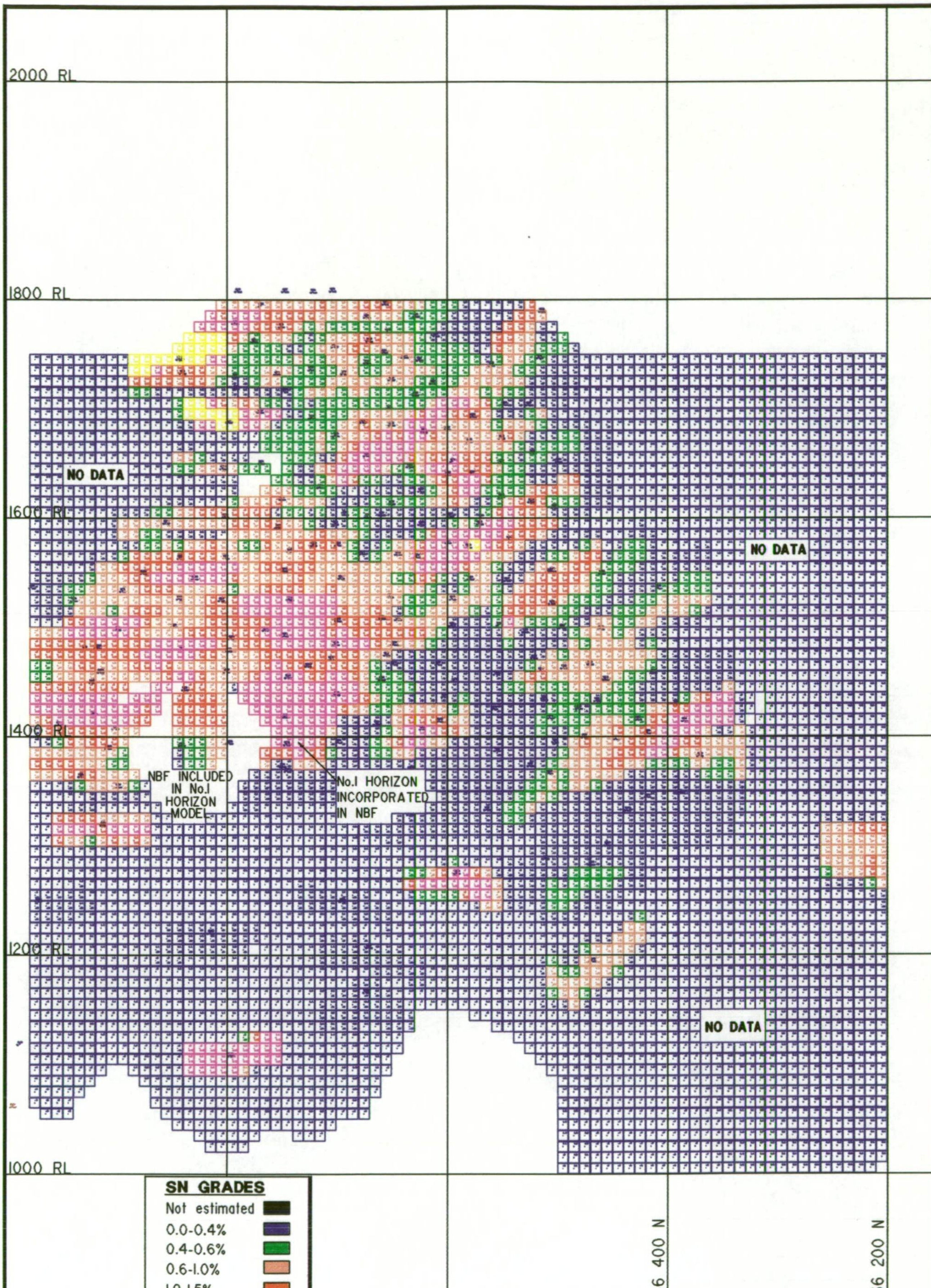
Standard Renison estimation techniques were used to model the tin grade distribution in the Rendeep area. The tin grade data used was gathered from the standard Renison XRF assaying of 150g pulverised splits of halved drillcore of average length 1m. Datamine software was used to create a three dimensional wireframed model of each mineralised dolomite horizon and the North Bassett Fault. Each wireframe was filled with cells with dimensions: x (east)=5m, y (north)=10m, z (elevation)=10m with sub-cell splitting to one fifth of this size. Estimation of tin grade was carried out by an inverse distance squared weighting method, using a search ellipse with dimensions: x (variable from 5 to 20m), y=45m , z=45m. The x-dimension chosen varied according to the relative thickness of the horizon being estimated. The three-dimensional block models were then converted to two-dimensional models in longitudinal projection for presentation purposes. Barren dolomite zones in the hangingwall of the North Bassett Structure were not modelled. The No. 3 Horizon was modelled but mineralisation is not sufficiently well developed to warrant further discussion.

4.3.2 Discussion of Results ...

Block-modelled tin grades for the North Bassett Fault, No. 1 Horizon and the No. 2 Horizon are shown in longitudinal projection in Figures 4.2, 4.3 and 4.4 respectively.

The North Bassett Fault (Fig. 4.2) contains a broad area of >1.0% Sn between 1350m RL and 1550m RL, north of 66650m N, corresponding to the location of the Rendeep Graben/Syncline (Chapter 3, Section 3.5.1.4) and the projected intersection of Fault Z with the North Bassett Fault. In the southern part of this area, some of the high grade is due to the incorporation of No. 1 Horizon replacement mineralisation into the North Bassett Fault. Other small patches of >1% Sn occur between 66550m N and 66700m N above 1550m RL, corresponding to areas where the No. 1 Horizon is incorporated into the North Bassett Fault. A broad area of low grade lies below 1350m RL, north of 66600m N, where the Renison Mine Sequence occurs on both sides of the North Bassett Fault. Lack of data to the south and north of the Rendeep area gives a false impression of low grades. There is a well-developed, linear trend of tin grades towards 2 o'clock, as viewed in longitudinal projection (Fig. 4.2). This trend is normal to the concave-east D3 dip-slip fold axis (Chapter 3, Section 3.5.2.2) and occurs with a wavelength of approximately 50 metres. The cause for this trend has not been studied but preferred sites for cassiterite deposition may result from local drops in pressure associated with necking and widening of the fault fissure due to asperities developed normal to the dip-slip movement direction.

The largest body of mineralisation in the Rendeep area is the Huon orebody, located



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TIN GRADE DISTRIBUTION IN NORTH BASSETT FAULT

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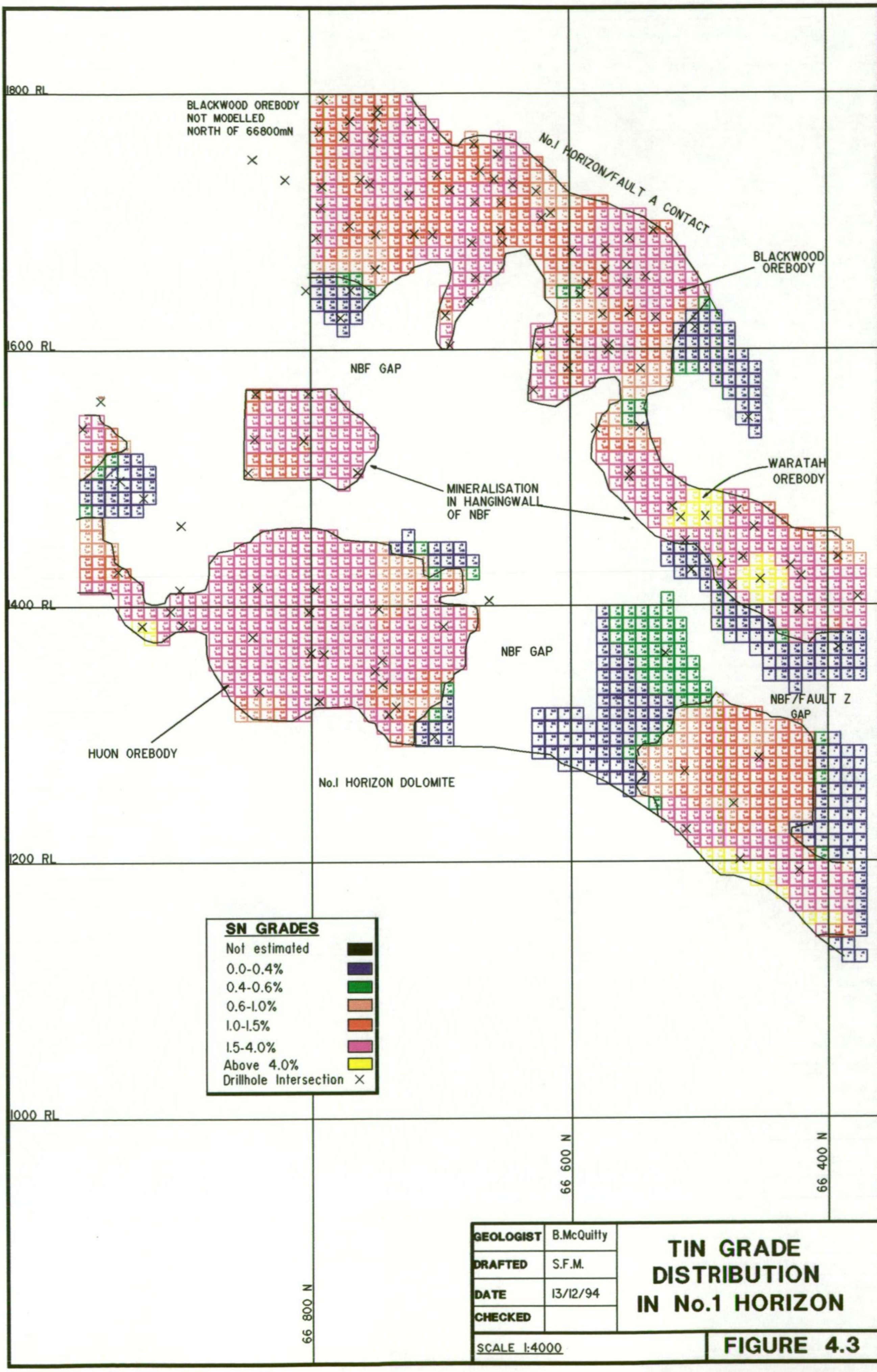
FIGURE 4.2



1800 RL
1600 RL
1400 RL
1200 RL
1000 RL
BLACKWOOD OREBODY NOT MODELLED NORTH OF 66800mN
No.1 HORIZON/FAULT A CONTACT
BLACKWOOD OREBODY
NBF GAP
MINERALISATION IN HANGINGWALL OF NBF
WARATAH OREBODY
NBF GAP
NBF/FAULT Z GAP
HUON OREBODY
No.1 HORIZON DOLOMITE
SN GRADES
Not estimated
0.0-0.4%
0.4-0.6%
0.6-1.0%
1.0-1.5%
1.5-4.0%
Above 4.0%
Drillhole Intersection
66 800 N
66 600 N
66 400 N
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DRAFTED S.F.M.
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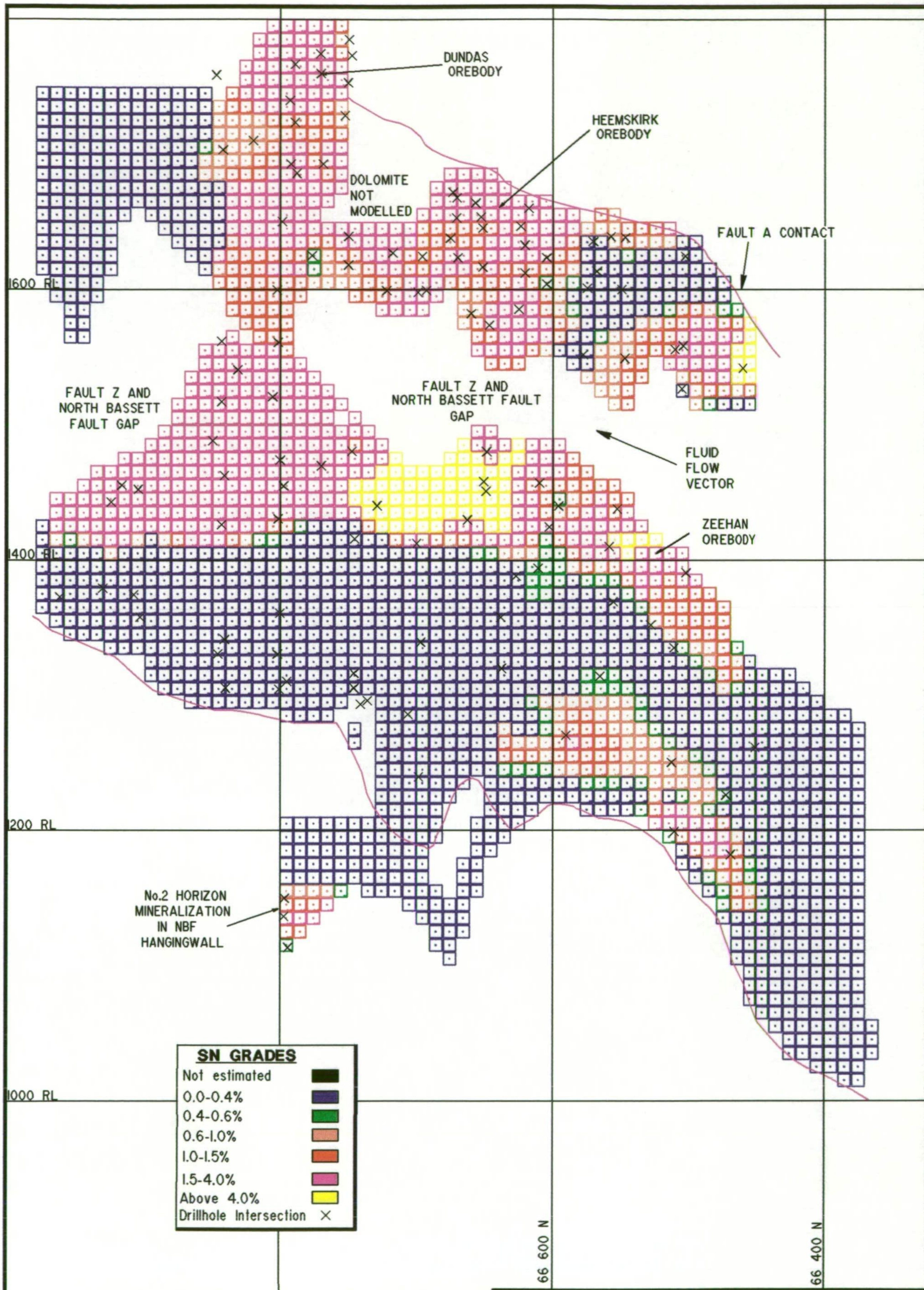
SCALE 1:4000
TIN GRADE DISTRIBUTION IN No.1 HORIZON
FIGURE 4.3



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TIN GRADE DISTRIBUTION IN No.2 HORIZON

FIGURE 4.4

G:\DRAFTED\GEOLOGY\PROJECTS\RENDEEP\RPT1194\RENDO083 between 1300m RL and 1450m RL, 66700m N and 66900m N (Fig. 4.3). This orebody lies directly above the Rendeep Graben/Syncline, where the North Bassett Fault transects the No. 1 Horizon (Appendix 1, sections 66750m N-66900m N). Almost the entire width of the No. 1 Horizon (up to 25m) has been mineralised. Above 1575m RL, mineralisation of the No. 1 Horizon, updip of its contact with the North Bassett Fault, formed the Blackwood orebody (Fig. 4.3). The Waratah orebody and a block of stratabound mineralisation directly above the Huon orebody (part of the Bruny South orebody; Figs. 4.3 & 1.3) have formed where drape folding of the No. 1 Horizon about Fault Z, prior to brittle reactivation of the North Bassett Fault, has resulted in portions of the No. 1 Horizon occurring in the hangingwall of the North Bassett Fault (Chapter 3, Section 3.5.2.1; Fig. 3.12). Further No. 1 Horizon stratabound mineralisation has been located near the No. 1 Horizon/North Bassett Fault contact below 1300m RL, south of 66550m N (Fig. 4.3; Appendix 1, sections 66375m N-66550m N). No. 1 Horizon mineralisation is still open to the north and south of the Rendeep area although mineralised widths at these margins are <5m.

The No. 1 Horizon (Fig. 4.3) occurs in close proximity to the North Bassett Fault throughout the Rendeep area and had ready access to mineralising fluids. Consequently, a high proportion of the No. 1 Horizon is mineralised.

Replacement mineralisation in the No. 2 Horizon occurs in the Heemskirk and Dundas orebodies and in the Zeehan orebody, respectively located above and below the projected intersection of Fault Z with the North Bassett Fault (Fig. 4.4). The Zeehan orebody is an extensive area of high grade mineralisation with a strike length of almost

500m, reaching a maximum width of 11m and maximum vertical extent of 140m on section 66800m N (Fig. 4.4; Appendix 1). The Zeehan orebody develops a long narrow tail to the south of section 66600m N which is marked by sub-economic widths and grades towards its southern end. Lower grade No. 2 Horizon mineralisation has also been located near the North Bassett Fault contact below 1300m RL, south of section 66600m N. The broad area of unmineralised No. 2 Horizon dolomite below the Zeehan orebody is located in the Rendeep Graben/Syncline and is separated from the North Bassett Fault by the full thickness of the Red Rock Member which is interpreted as having restricted ingress by hydrothermal fluids.

4.4 MODELLING OF FLUID MIGRATION USING OXYGEN ISOTOPES

4.4.1 Method ...

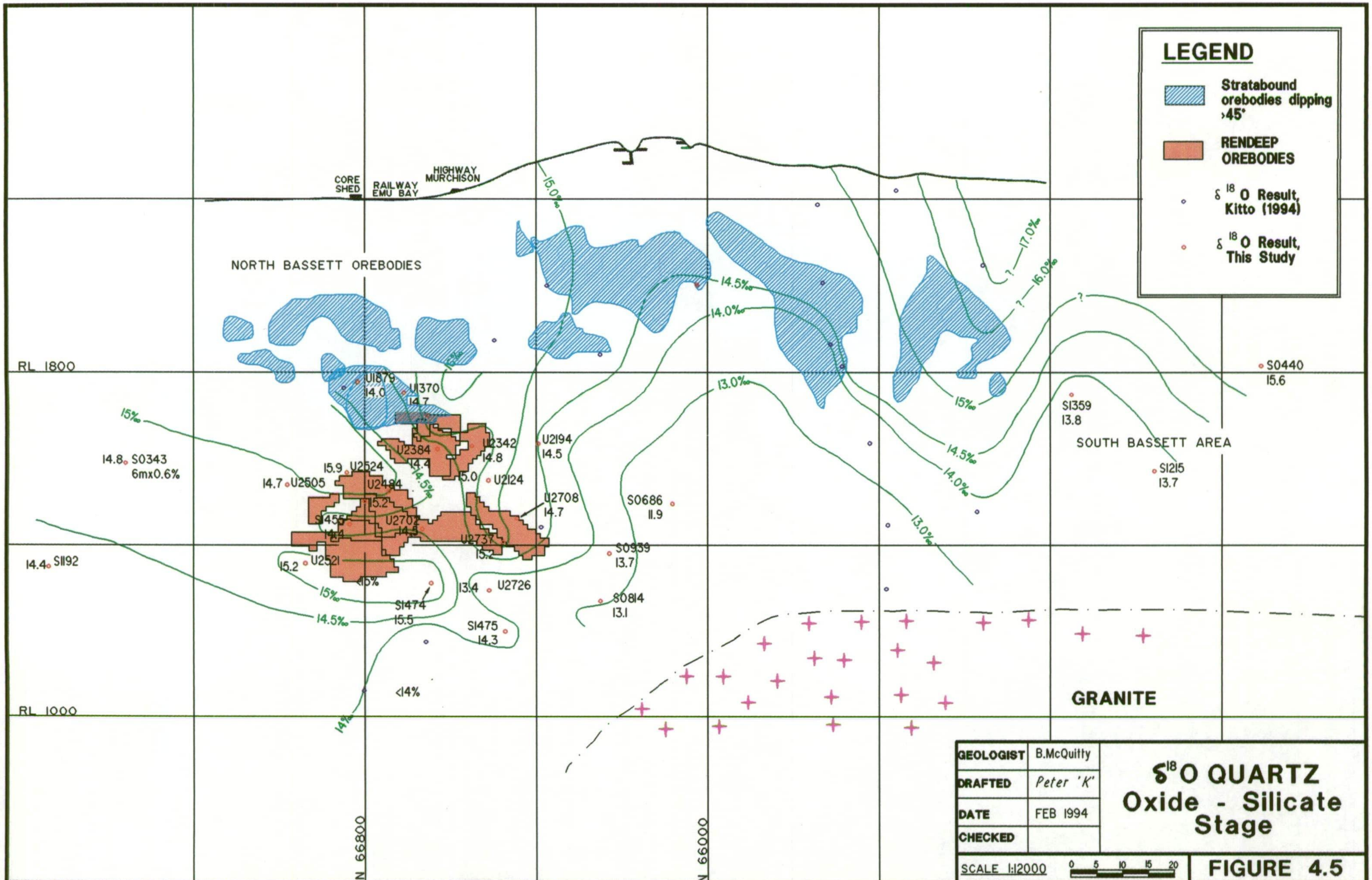
Samples of hydrothermal quartz from the Oxide-silicate Stage of mineral paragenesis were selected from drillcore intersections. Sampling was conducted under the supervision of Paul Kitto to ensure compatibility with previous work. Twenty-five samples were selected from the Federal-Bassett Fault for analysis. Three samples were from south of the Deep Federal area, the remainder were from the Rendeep area and and its possible northern and southern extensions. Sampling was designed to cover as broad an area as possible. Hydrothermal quartz samples were submitted to the oxygen isotope laboratory at the Geology Department, University of Tasmania, where conventional procedures were used for analysis of oxygen isotope values in quartz (Clayton and Mayeda, 1963). Further details on the analytical pocedure are to be found in Kitto (1994). Results are expressed in the standard δ(‰) notation, relative to Standard Mean Ocean Water (SMOW) and are quoted to a precision of ± 0.2‰.

4.4.2 Discussion of Results ...

The $\delta^{18}O_{qz}$ results, which fall in a range from 11.9‰ to 15.9‰, with a mean of 14.5‰, are presented in Appendix 2. Figure 4.5 shows the results plotted and contoured in longitudinal projection relative to the position of known stratabound and Rendeep orebodies. The results of earlier sampling by Kitto (1994) were taken into account by the contouring. No attempt has been made to calculate $\delta^{18}O_{fluid}$ values. Kitto showed that there was a 1‰ increase in $\delta^{18}O_{fluid}$ up the Federal-Bassett Fault which he thought may be due to isotopic exchange between dolomite horizons and the fluid by way of water-rock interaction. Despite this slight shift in $\delta^{18}O_{fluid}$ values, $\delta^{18}O_{qz}$ values serve adequately to define both broad and relatively local hydrothermal palaeoflow directions.

The $\delta^{18}O_{qz}$ contours in Figure 4.5 show a concentric distribution about the Pine Hill Granite and a systematic increase in $\delta^{18}O_{qz}$ up the Federal-Bassett Fault, indicating the hydrothermal palaeoflow directions. By comparison, five $\delta^{18}O_{qz}$ values for the Pine Hill Granite obtained by Kitto (1994) had a range from 10.0‰ to 11.2‰ (mean 10.5‰). Local upflow zones are indicated:

1) in the Rendeep/North Bassett area,
2) between the Rendeep and Deep Federal area, and



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3) in the South Bassett area, (Fig. 4.5).

The largest upflow zone is centrally located to the deposit and lies directly above the shoulder of the Pine Hill Granite. The upflow zone in the Rendeep area forks, with one zone continuing through to the North Bassett orebodies (Fig. 4.6), the other heading north towards the poorly-drilled area north of the Rendeep area. The Rendeep upflow zone is discussed in detail in Section 4.7.1.

Known areas of stratabound mineralisation that lie adjacent to the Federal-Bassett Fault fall beween the 14‰ and 16‰ contours. With the exception of the Rendeep/North Bassett area, the lower limit of stratabound mineralisation coincides with the faulting out of the No. 2 and No. 3 Horizons against the Federal-Bassett Fault. Therefore, any suggestion that the 14‰ and 16‰ contours serve to define fields suitable for replacement mineralisation in dolomite horizons adjacent to the Federal-Bassett Fault must be tentative. Further drilling of the Renison Mine Sequence closer to the granite in the Rendeep area will test this relationship.

4.5 MODELLING OF FLUID MIGRATION USING SULPHUR ISOTOPES

4.5.1 Method ...

Samples of pyrrhotite from the Main Sulphide Stage of the mineral paragenesis were selected from drillcores. Sampling was again supervised by Paul Kitto to ensure compatibility with previous work. Twenty-three samples were selected from the

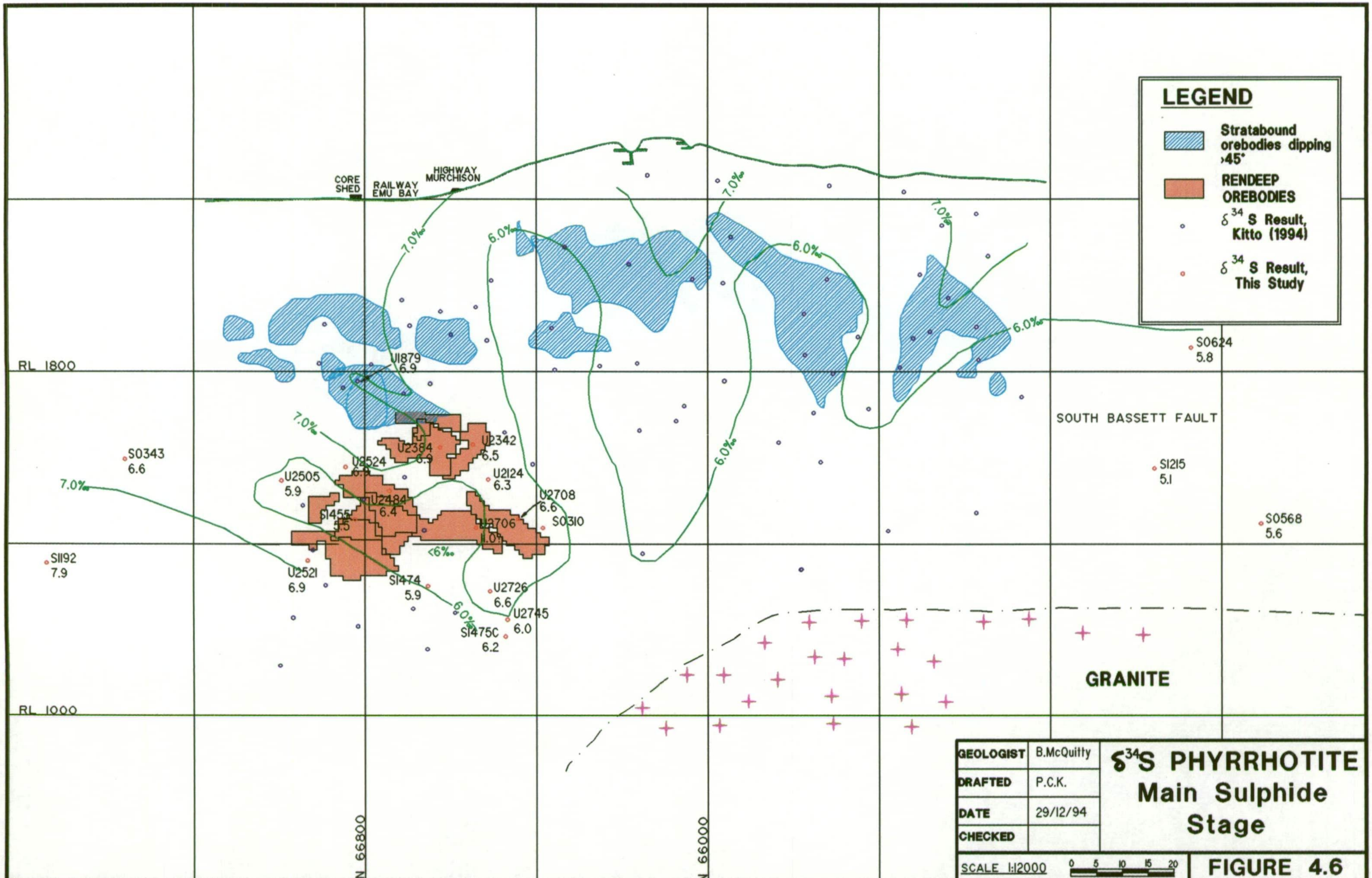
Federal-Bassett Fault for analysis. Three samples were from the South Bassett area (Fig. 4.6), one from the Owen-Meredith area (locality, Fig. 2.2) and the remainder were from the Rendeep/North Bassett area. Conventional sulphur isotope analyses were performed at the University of Tasmania's Central Science Laboratory on hand drilled pyrrhotite separates. Further details on the standard analytical procedure can be found in Kitto (1994). Results are expressed in the standard δ(‰) notation, relative to Canyon Diablo Troilite (CTD) and are quoted to a precision of ± 0.2‰.

4.5.2 Discussion of Results ...

The $\delta^{34}S_{po}$ results range from 3.5‰ (in the Owen-Meredith area) to 7.9‰, with two anomalous, possibly spurious results of 11.0‰ and 12.5‰. The mean, calculated excluding the two possibly spurious results and the Owen-Meredith result is 6.3‰ and the standard deviation is 1.5‰. The results are presented in Appendix 2. The results plotted and contoured in longitudinal projection in Figure 4.6. The results of earlier sampling by Kitto (1994) were included in the contouring. Kitto (op. cit.) considered the relatively close range of the sulphur isotope data to reflect a homogeneous magmatic source.

The contoured $\delta^{34}S_{po}$ results in Figure 4.6 show a systematic increase away from the Pine Hill Granite. There are three distinct upflow zones:

1) in the Rendeep area, corresponding to the location of the Rendeep Graben structure,



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2) south of the Rendeep area, corresponding to the projected intersection of Fault A with the North Bassett Fault,

3) in the Federal area, corresponding to the dilational jog on the Federal Fault (Kitto, 1994).

A zone of low $\delta^{34}S_{po}$ results persists north of the Rendeep area as defined by drillhole S343 (Fig. 4.6). A similar pattern was recorded by the oxygen isotopes (Fig. 4.5) and coincides with a trend of elevated tin grades in the North Bassett Fault (Fig. 4.2) and the No. 1 Horizon (Fig. 4.3). The 6‰ contour, which defines a zone of low $\delta^{34}S_{po}$ results in the Rendeep area, closes off towards the granite. However the analytical precision of ± 0.2‰ should be considered when interpreting the contoured data.

4.6 Modelling Of Fluid Migration Using Fluid Inclusion Homogenisation Temperatures ...

4.6.1 Method ...

Twenty-five specimens of Oxide-silicate Stage mineralisation from drillcore intersections with the Federal-Bassett Fault were selected for doubly polished thin section preparation. In Oxide-silicate Stage mineralisation, primary fluid inclusions can be found in zoned cassiterite and quartz crystals. The majority of fluid inclusions at Renison are small, being typically <5µm in diameter (Patterson, 1979; Davies, 1985; Holyland, 1987; Kitto, 1994). Difficulties were encountered in locating workable fluid inclusions due to:

1) the thickness of wafers causing the opacity of cassiterite to obscure potentially workable inclusions,

2) numerous flaws in crystals, particularly quartz, resulting from brittle reactivations on the Federal-Bassett Fault,

3) numerous secondary and pseudo-secondary inclusions, resulting from necking during deformation related to (2) above, and

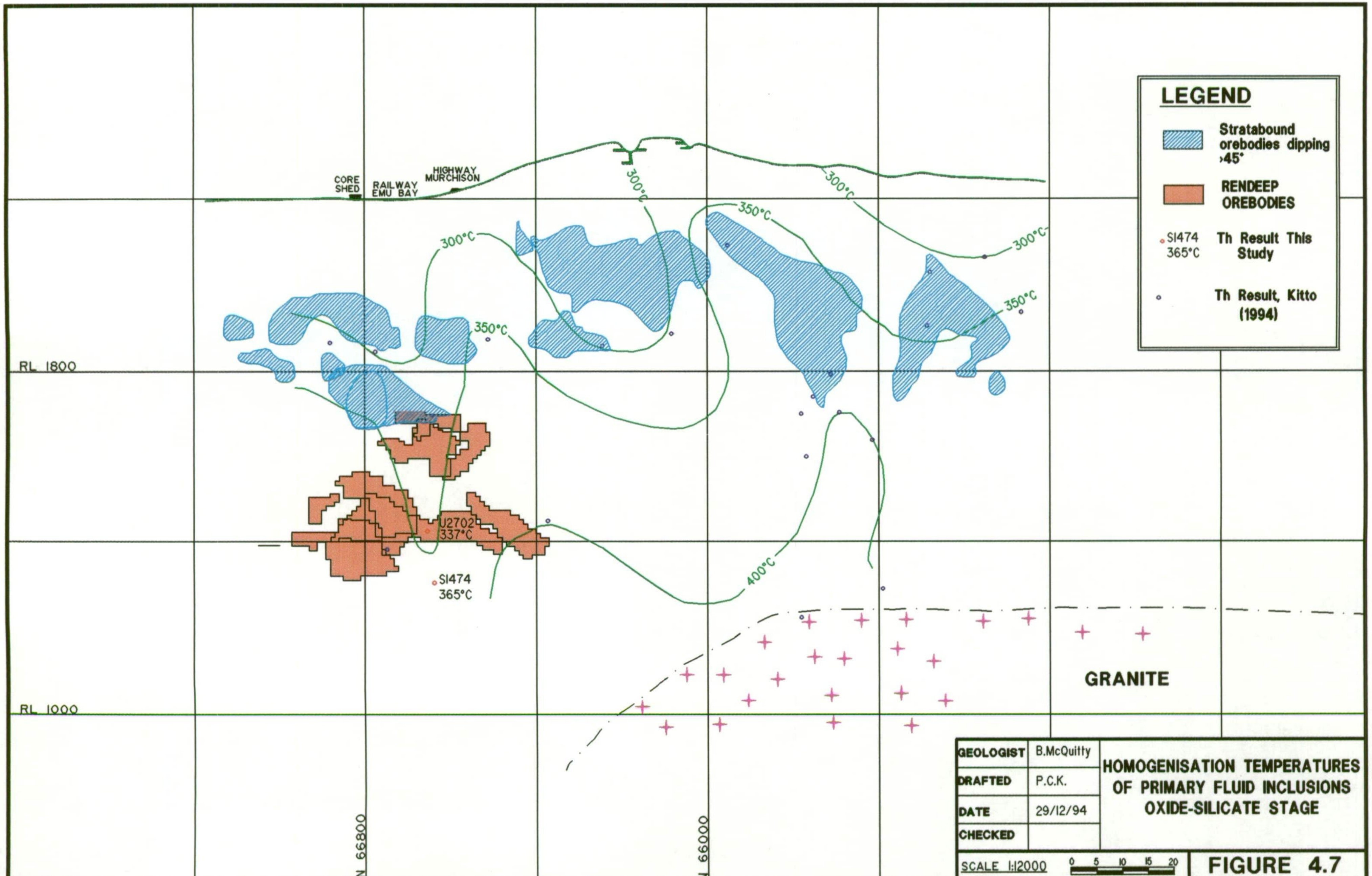
4) the small size of inclusions.

Ten specimens were selected for heating and freezing experiments on a total of 15 chips. Microthermometry was conducted at the University of Tasmania on a modified USGS gas-flow heating and freezing stage. The thermocouple meaurements are calibrated against the triple point of CO_2 (-56.6°C), the freezing point of water (0.0°C), and the critical point of water (374.1°C) in synthetic fluid inclusions. Precision of measured temperatures are ±1.0°C for heating and ±0.3°C for freezing. During microthermometry, emphasis was placed on recording homogenisation temperatures because these represent minimum trapping temperatures which can be used to define the patterns of hydrothermal palaeoflow.

4.6.2 Discussion of Results ...

Results of heating and freezing runs on 34 fluid inclusions are presented in Appendix 3. All fluid inclusions were hosted by quartz and were of the liquid + vapour type, with vapour <50% by volume. Only 6 primary fluid inclusions were positively identified using criteria defined by Reynolds (1990), e.g. forming on crystal growth zones. Some inclusions that occurred on growth zones and had euhedral negative crystal shapes were thought to be primary, but yielded homogenisation temperatures much lower than those of other primary inclusions in this study and that of Kitto (1994). These inclusions are inerpreted to be pseudosecondary. Homogenisation temperatures have not been corrected for pressure. Critical behaviour and palaeosurface estimates indicate hydrostatic conditions, requiring a maximum pressure correction of ~15°C for a 10 wt. % NaCl solution, which is considered to be within the range of experimental error (Kitto, *op. cit.*).

Of the 6 positively identified primary fluid inclusions, one decrepitated at 344.8°C before homogenising and the remaining 5 were from only 2 drillholes. Hence only 2 results could be plotted on the longitudinal projection (Fig. 4.7), which includes 21 results from Kitto's (1994) study. The contoured data points show a broad decrease in temperature up theFederal-Bassett Fault. Two upward projections of the isotherms correspond to the Federal area and the projected Fault A/North Bassett Fault intersection to the south of the Rendeep aera. The two data points from this study are insufficient for resolution of more detailed fluid migration patterns in the Rendeep area.



HOMOGENISATION TEMPERATURES OF PRIMARY FLUID INCLUSIONS OXIDE-SILICATE STAGE

FIGURE 4.7

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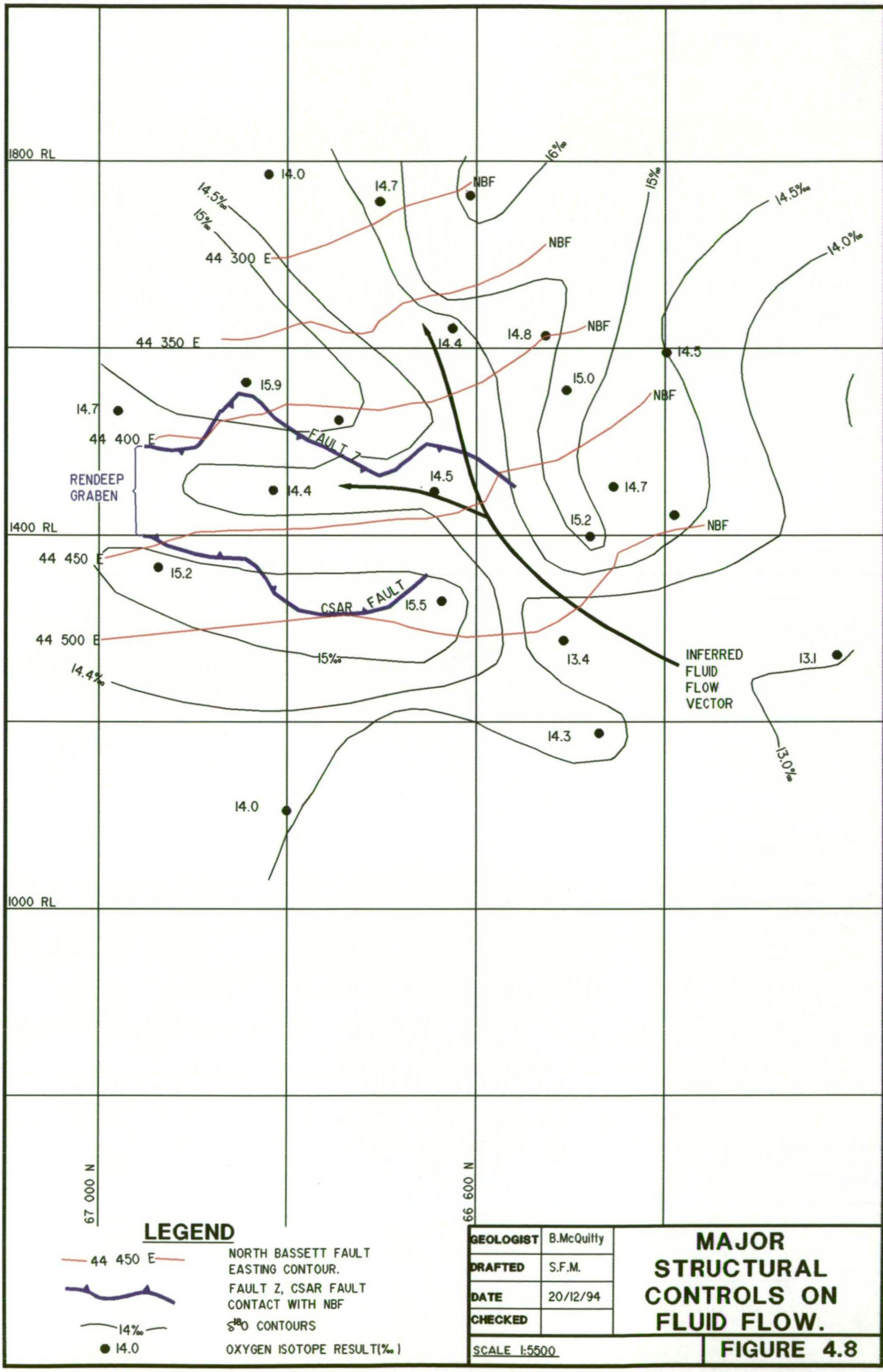
4.7 STRUCTURAL CONTROLS TO MINERALISATION ...

4.7.1 Major Structural Controls ...

On a regional scale, metal and stable isotopic zonation patterns confirm that the Pine Hill Granite stock was the major structure largely responsible for the distribution of mineralisation in the Renison district (Kitto, 1994). Tensile fractures developed over the regions of maximum curvature in the surface of the Pine Hill Granite, e.g. the Federal-Bassett Fault (Leaman, 1990; Lea, 1991; Kitto, 1994), which became the major focus for hydrothermal fluids.

The Rendeep orebodies lie between 400m and 900m updip and to the north of the region of maximum curvature in the Pine Hill Granite surface which is centrally located under the Renison deposit (Fig 4.5). Coincident low $\delta^{18}O_{qz}$ and $\delta^{34}S_{po}$ values in Figures 4.5 and 4.6 respectively, indicate a hydrothermal fluid upflow zone along the North Bassett Fault, extending from the region of maximum curvature in the granite surface towards the Rendeep area. Figure 4.8 (longitudinal projection) shows the $\delta^{18}O_{qz}$ contours of Oxide-silicate Stage mineralisation on the North Bassett Fault in the Rendeep area in relation to the Rendeep Graben/Syncline (between the projected contacts of Fault Z and the Csar Fault with the North Bassett Fault) and the concave-east fold in the North Bassett Fault (defined by footwall easting contours). The lowest $\delta^{18}O_{qz}$ values coincide with the axis of the concave-east fold and the Rendeep Graben/Syncline. High tin grades are also associated with these structures (Figs. 4.2, 4.3 & 4.4).

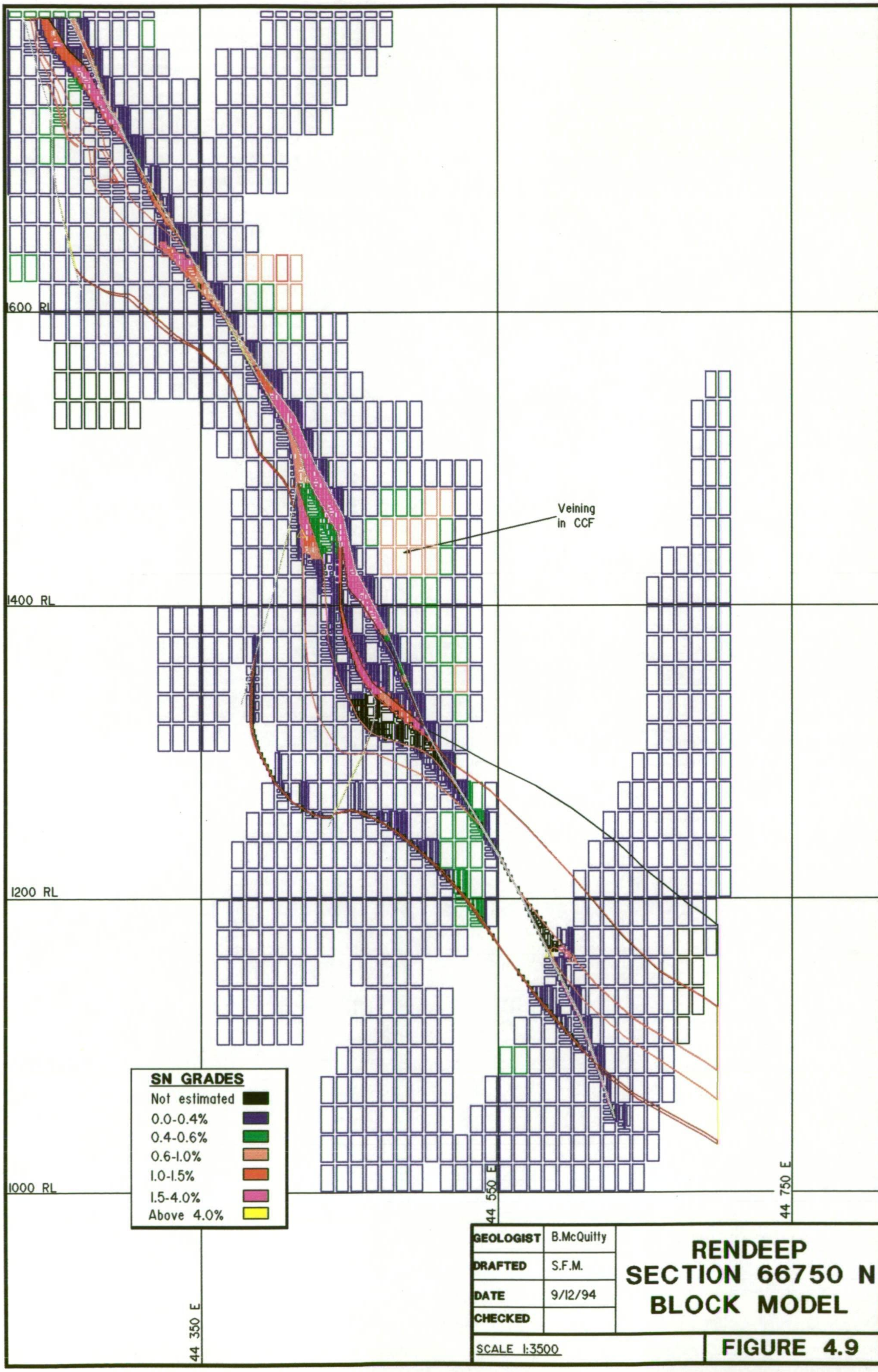


MAJOR STRUCTURAL CONTROLS ON FLUID FLOW.

FIGURE 4.8

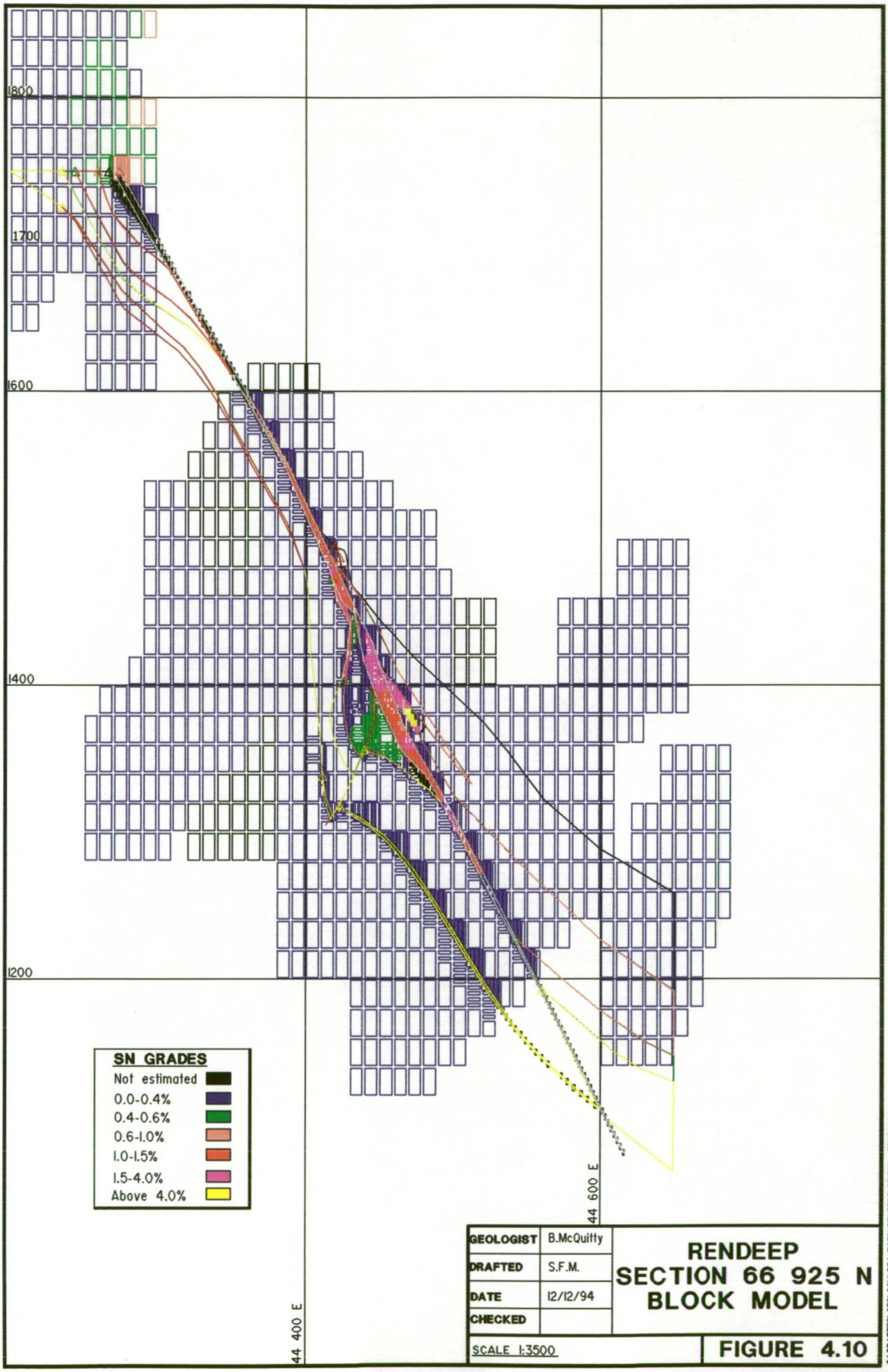
Figures 4.9 and 4.10 show cross-section slices of block modelled tin grades, including background grades, for a wireframe of all major mineralised zones in the Rendeep area. Perimeters of the structure are superimposed on cells with dimensions z=20m and x=10m which are coloured by tin grade. More detail of the geological structure is revealed in Appendix 1, sections 66750m N and 66925m N. The North Bassett Fault, the narrow linear feature dipping diagonally form west to east, contains high tin grades where it locally widens above the Rendeep Graben /Syncline (between 1300m RL and 1500m RL), corresponding to the point where Fault Z diverges from the North Bassett Fault. This pattern is consistent for a strike length of over 200m. Veining developed in Crimson Creek Formation above the Rendeep Graben/Syncline is represented by a broad area of 0.4% to 1.0% Sn in Figure 4.9. Mineralisation of the Renison Mine Sequence, principally replacement of the dolomite horizons, occurs adjacent to the widest regions of the North Bassett Fault.

Strain transferral from the North Bassett Fault onto Fault Z during D3 dip-slip deformation (Chapter 3, Sections 3.5.1.4 & 3.5.2.1) resulted in dilation of the North Bassett Fault above the Rendeep Graben/Syncline. Hydrothermal fluids spread to replace the adjacent Renison Mine Sequence rocks, facilitated by the unlocking of bedding planes by folding and flexural slip. Strain transferral from the North Bassett Fault onto Faults A and Z during D3 dip-slip deformation also produced the concave-east fold in the North Bassett Fault which has served to localise mineralisation into the Rendeep and North Bassett areas. The fold axial plunge and trend is similar to that of the jog on the Federal-Bassett Fault which localised hydrothermal palaeoflow in the central mine area (Kitto, 1994; Chapter 3, Section 3.5.2.2).



RENDEEP
SECTION 66750 N
BLOCK MODEL

FIGURE 4.9



RENDEEP
SECTION 66 925 N
BLOCK MODEL

FIGURE 4.10

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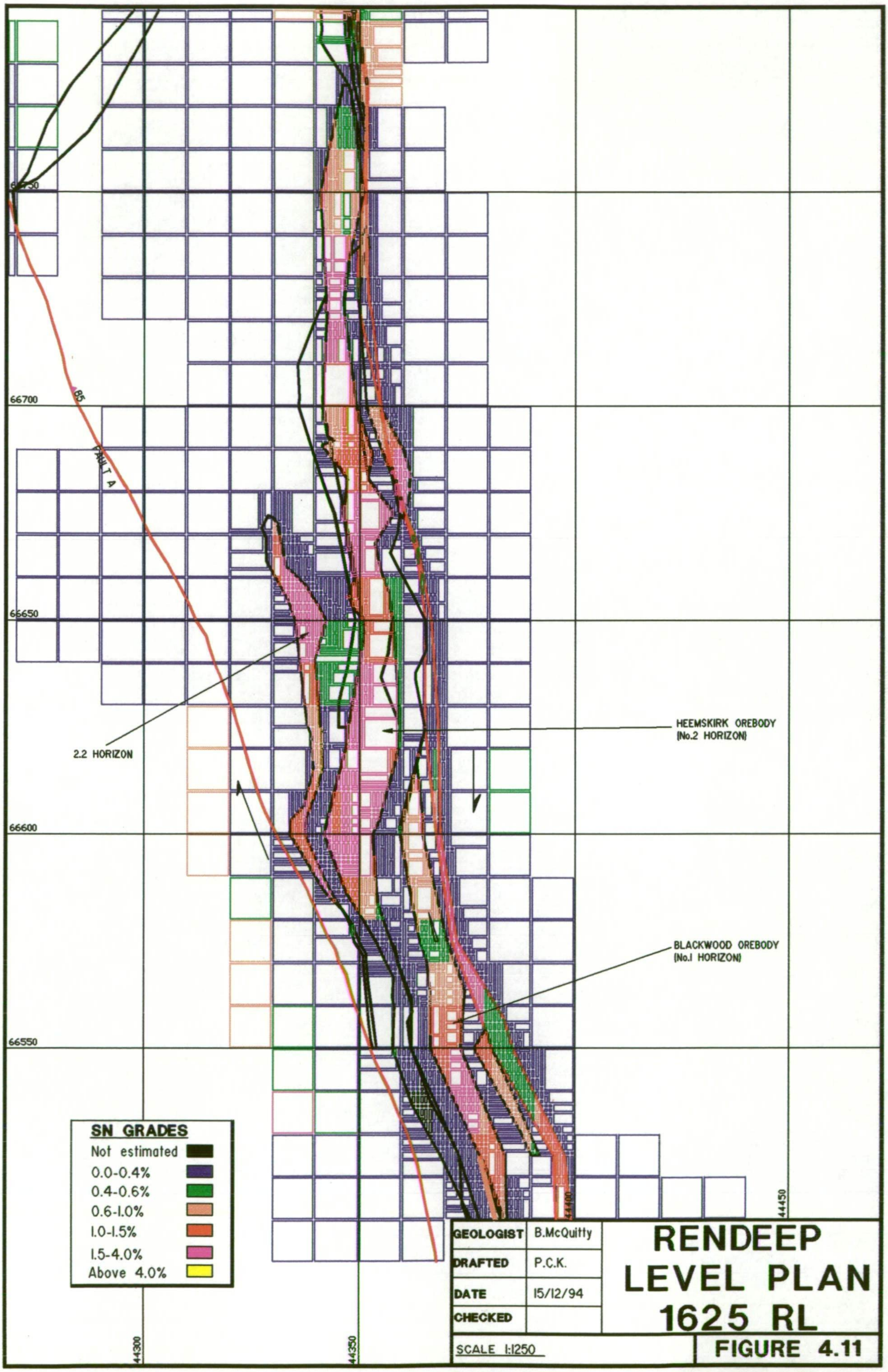
4.7.2 Local Structural Controls ...

Figure 4.11 shows a block model of tin grades in level plan at 1625m RL (refer to Figure 3.15 for an explanation of the geology). High tin grades occur in the widest parts of the No.s 1, 2 and 2.2 Horizons which have been kink-folded by north-south shortening during D3 strike-slip deformation (Chapter 3, Section 3.5.2.3). A patch of 0.4-0.6% Sn (green) between the 2.2 Horizon and the No. 2 Horizon represents mineralisation of the upper Renison Bell Member and occurs in the region of maximum north-south shortening. The proximity of carbonates to the North Bassett Fault, the main hydrothermal fluid conduit, is also an important local control to stratabound mineralisation.

Bedding plane partings act as important local controls to mineralisation. Stratabound mineralisation frequently occurs at the faulted contact of dolomite horizons with more siliceous wallrocks in the Rendeep area (Fig. 3.11). Plate 4.4 shows a sample of a single bed of Red Rock Member dolomite from the Blackwood 1670 sill access, sliced vertically, parallel to the dip azimuth. A sharp replacement front is defined at the contact of dolomite with pyrrhotite. Mineralisation occurs preferentially at the hangingwall and footwall contacts which have slickensided chorite coatings. Unlocking of bedding planes during folding and bedding-parallel faulting created sites for local hydrothermal fluid ingress.



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RENDEEP LEVEL PLAN 1625 RL

FIGURE 4.11

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Plate 4.4 Sample of single Red Rock Member dolomite bed from Blackwood 1670 Sill access, showing preferential replacement of dolomite by pyrrhotite along bedding planes (top and bottom of sample). Hydrothermal fluids gained access along bedding-parallel joints and faults. This pattern is commonly observed throughout the Rendeep area.

4.8 PRESSURE AND TEMPERATURE CONTROLS TO MINERALISATION ...

Large (1989), in a study of the exploration criteria for replacement-style tin deposits, noted that high grade massive pyrrhotite deposits (e.g. Renison, Cleveland, Mt. Bischoff and Severn) are developed at distances of 500-1500m from the Devonian source granites. At distances of less than 500m, magnetite and magnetite-pyrrhotite skarns (e.g. Mt. Lindsay and St. Dizier deposits) dominate. At the southern end of the Rendeep area, replacement-style, massive pyrrhotite and semi-massive pyrrhotite + talc mineralisation occurs at distances of 400m from the Pine Hill Granite. Replacement mineralisation is localised about the North Bassett Fault, minor fractures and bedding plane contacts (e.g. the No. 2 Horizon in drillhole U2720, Plate 4.5; Appendix 1, section 66625m N), and is rarely developed throughout the entire dolomite horizon.

The following sections briefly investigate the possibility that the brittle-ductile transition in dolomites of the Renison Mine Sequence may account for the restricted extent of replacement mineralisation closer to the Pine Hill Granite..

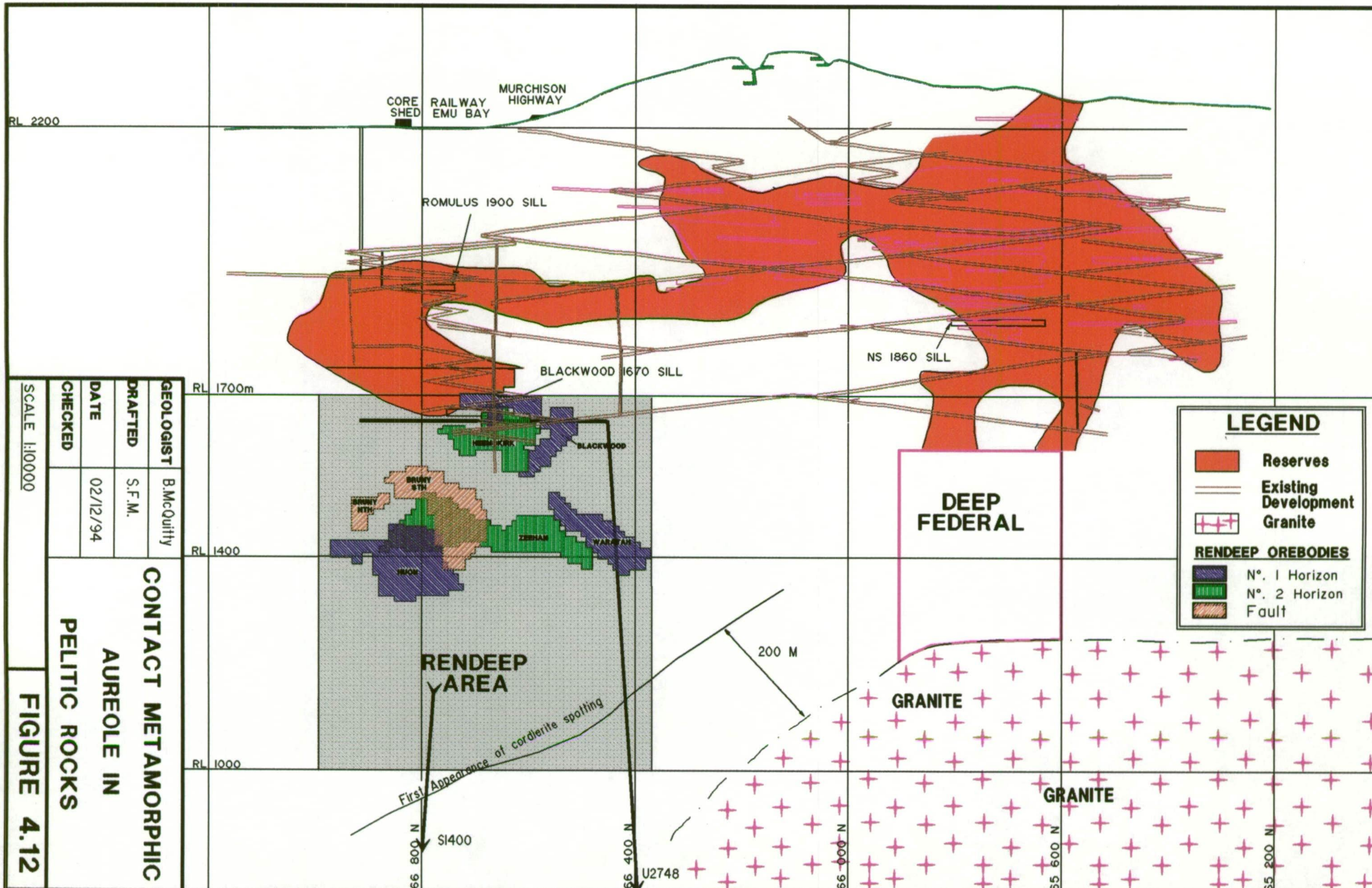
4.8.1 Pressure Estimates ...

Depth estimates of 2-4km for the emplacement of the Pine Hill Granite have been discussed in Section 3.2.1.3. All stages of mineral paragenetic sequence are believed to have formed under a hydrostatic pressure regime (Kitto, 1994). Hydrostatic pressure estimates of the upper part of the Renison deposit at the time of formation range from

~400 bars (Davies, 1985) to 300 - 850 bars (Holyland, 1987), based on fluid pressures in CO_2-rich fluid inclusions. Kitto (*op. cit.*) estimated a hydrostatic pressure range of 132 - 336 bars based on critical behaviour observed in a group of secondary inclusions in the upper part of the deposit and estimated a lithostatic pressure of 500 - 1000 bars (50-100 MPa) for the formation of the the Renison deposit. The Rendeep area would fall towards the higher end of this range of pressure estimates. Pressures are likely to have been elevated above lithostatic pressures in the high strain region surrounding the Pine Hill Granite during intrusion. Measured strengths of rocks in the Rendeep area, which have been subject to deviatoric stresses during granite emplacement, are above 100 MPa (Chapter 2, Section 2.6).

4.8.2 Temperature Estimates ...

Intrusion of the Pine Hill Granite at solidus temperatures <650°C (Bajwah *et al.*, in press) produced thermal metamorphism and boron metasomatism up to 800m radially from the granite contact under the Renison mine and more than 1000m distant along major fault zones (Patterson, 1979). Early metasomatism produced skarn mineralisation in limestone units of the Crimson Creek Formation at Pine Hill at temperatures of 400-600°C (Manly, 1982). Thin section evidence suggests ductile deformation accompanied boron metasomatism in the Rendeep area (Plates 3.10 & 3.26). Contact metamorphism of pelitic rocks produced a halo of distinctively spotted texture, due to mica development after cordierite(?), up to 200m from the Pine Hill Granite surface beneath the Rendeep area, recognised in drillholes S1400 and U2748 (Fig. 4.12). Drillhole U2748 (Appendix 1, section 66425m N) intersected the No. 2 Horizon dolomite at a distance of



CONTACT METAMORPHIC AUREOLE IN PELITIC ROCKS

FIGURE 4.12

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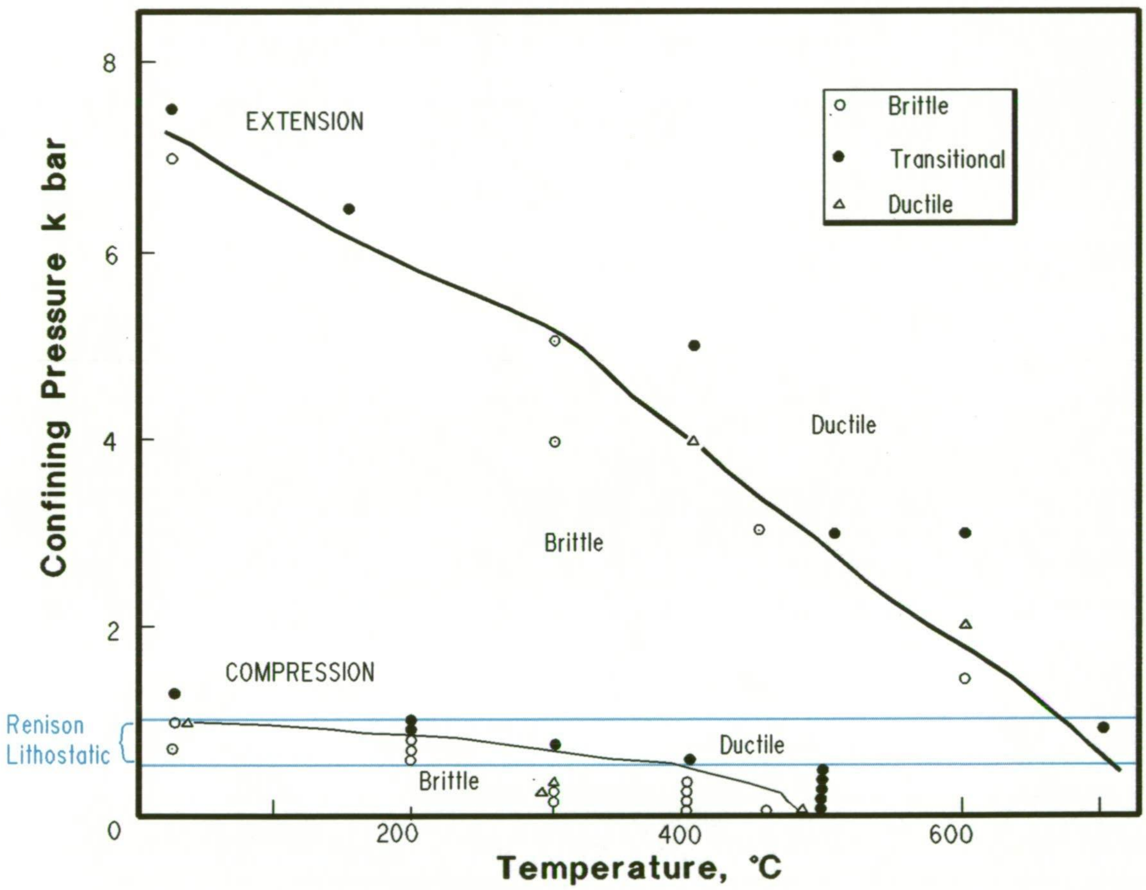
270m from the Pine Hill Granite. The dolomite was recrystallised and contained minor magnetite developed in stylolites. It is considered transitional to formation of a magnetite skarn.

The commencement of hydrothermal activity coincided with the reactivation of the Federal-Bassett Fault as a brittle structure after a period of cooling and crystallisation of the outer shell of the Pine Hill Granite (Kitto, 1994; Chapter 3, Section 3.6.3). The initial temperature of the hydrothermal fluids exolved from the granite magma was ~450°C (Kitto, 1994). Fluids cooled to ~350°C in the Rendeep area as indicated by the homogenisation temperatures for primary fluid inclusions from Oxide-silicate Stage mineralisation (Fig. 4.8). Wallrock temperatures immediately adjacent to major fluid upflow zones on the North Bassett Fault could be expected to approach hydrothermal fluid temperatures.

4.8.3 Brittle-ductile Transition in Dolomites ...

Relatively little study has been carried out on the brittle-ductile transition in dolomite other than at room temperature (Paterson, 1978). Heard (1960) carried out a thorough study of the brittle-ductile transition in Solnhofen Limestone under extension and compression for a range of temperatures and pressures. Figure 4.13 which summarises the results of Heard's study, shows that the Solnhofen Limestone attains ductility under compression above 100 MPa (1 Kbar) at room temperature. Above 500°C ductile behaviour is attained without confining pressure. The field of Renison lithostatic pressure estimates, at time of formation of the deposit, is plotted in Figure 4.13. The



Brittle-ductile transition in Solnhofen limestone, in compression and in extension as a function of temperature. (After Heard, 1960)

GEOLOGIST	B.McQuitty	**BRITTLE-DUCTILE TRANSITION IN SOLNHOFEN LIMESTONE**
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SCALE 1:NOT TO SCALE		**FIGURE 4.13**

C:/DRAFTED/GEOLOGY/PROJECTS/RENDEEP/RP171194/REND0073 lithostatic pressure in the Rendeep area would plot towards the top of this range. Using this experimental data, ductile behaviour would be predicted for limestone in the Rendeep area above ~300°C. The rheological behaviour of dolomite is likely to differ from the Solnhofen Limestone, however, because the confining pressure at which the brittle-ductile transition is achieved in dolomite relative to limestone at room temperature is higher (1-2 Kbar; Handin and Hager, 1957).

Plates 4.6 and 4.7 show textures in the No. 2 Horizon dolomite which are interpreted as evidence of ductile deformation. Deformed early carbonate veins in the dolomite from drillhole U2720 occur 1m from replacement mineralisation which is localised around the hangingwall contact with the Red Rock Member. Plate 4.7 shows flattening strain developed in recrystallised dolomite which is deformed around an actinolite crystal. These ductile deformation textures are thought to have formed during early D3 dip-slip deformation, based on evidence and arguments presented in Chapter 3, Sections 3.5.2.5 & 3.6.3.

A transition to ductile behaviour in dolomite is tentatively proposed as the process resulting in restriction of the extent of replacement mineralisation closer to the granite in the Rendeep area. This occurs by:

1) limiting the amount of brittle macro-structures available for hydrothermal fluid ingress, and

2) limiting the extent of fluid/dolomite interaction by supressing crack propagation

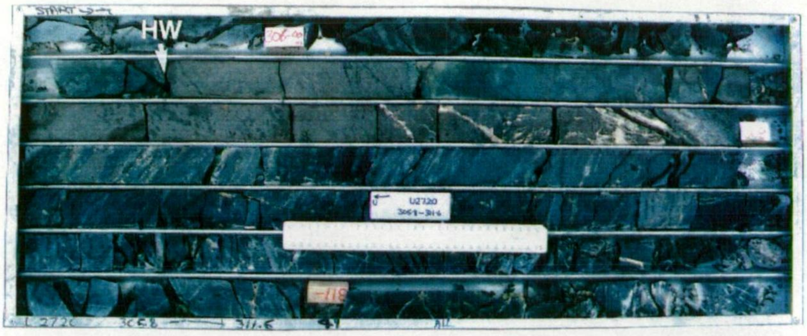


Plate 4.5 Drillcore from U2720, 305.8-311.6m, location 66625m N, 1380m RL, (560m from granite) showing replacement by pyrrhotite is restricted to hangingwall of No. 2 Horizon. The hangingwall contact with overlying Red Rock Member (HW) is faulted. Later carbonate veins cut the pyrrhotite. Earlier carbonate veins show evidence of ductile deformation (Plate 4.6).

Plate 4.6 U2720, close-up of previous plate, showing early carbonate veins (arrowed) that have boudined and necked in a manner that suggests ductile deformation.

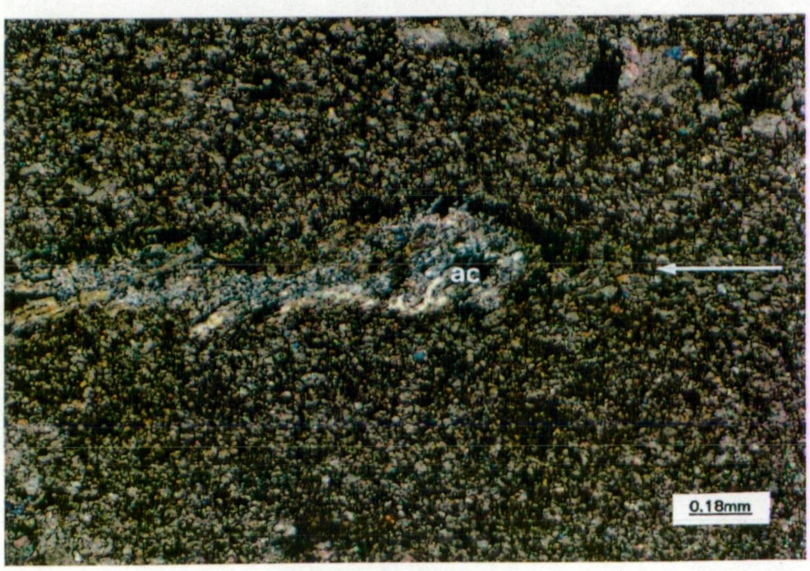


Plate 4.7 Recrystallisation textures in dolomite, showing preferred orientation of dolomite crystals which conform to the shape of the actinolite (ac) phenocryst. Drillhole U2512, 321.9m, 66700m N 1330m RL (600m from granite), x-polars.

in the dolomite during replacement reactions.

The brittle-ductile transition in dolomite is expected to be zoned around the Pine Hill Granite and along major faults and to have retreated with cooling of the pluton, to about 400m above the granite surface at the commencement of hydrothermal activity. Further drilling of the Renison Mine Sequence closer to the Pine Hill Granite is required to test whether ductile behaviour in dolomite limits the development of replacement mineralisation.

4.9 TIMING OF MINERALISATION RELATIVE TO DEFORMATION ...

The commencement of hydrothermal activity in conjunction with brittle reactivation on the Federal-Bassett Fault has been established from vein paragenesis relationships by Kitto (1994) (Section 4.2) and from evidence suggesting that brittle reactivation of the Federal-Bassett Fault postdated the crystallisation of the outer shell of the Pine Hill Granite (Chapter 3, Sections 3.4.1 & 3.6.3). Plates 3.10 & 3.26 provide evidence that ductile deformation accompanied boron metasomatism, while Plates 3.8 & 3.9 show mineralised veins crosscutting earlier ductile fabric in Fault A and Fault Z, respectively.

Plates 4.8 & 4.9 present further evidence of hydrothermal veins overprinting earlier ductile fabric associated with Faults A and Z. In Plate 4.8, early ductile deformation is displayed by grain boundary migration of quartz in a recrystallised sandstone clast. A crosscutting pyrrhotite vein has opened in a direction parallel to the extension direction of the quartz grains. Plate 4.9 shows a hydrothermal Fe-chlorite vein cross-cutting an

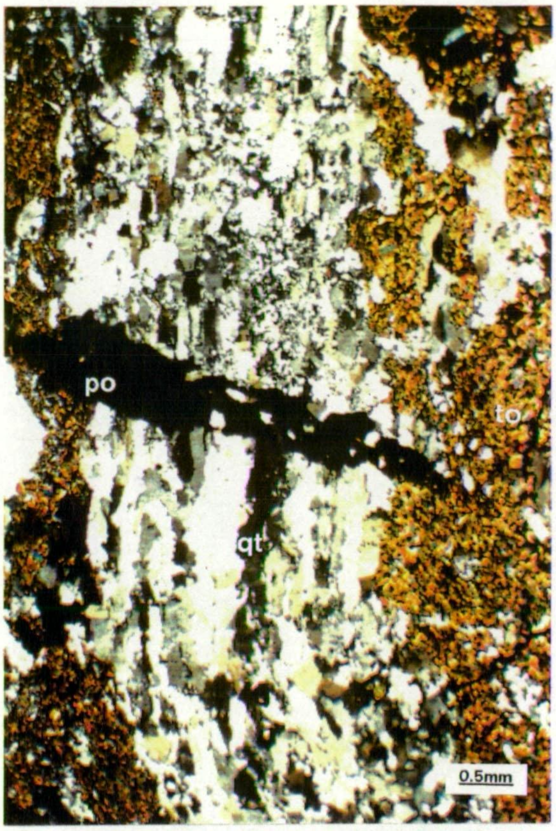


Plate 4.8 Recrystallised sandstone clast, exhibiting migration of quartz (qt) grain boundaries in extensively tourmalinised matrix (to). A pyrrhotite vein (po) crosscuts the direction of extension of the quartz grains. Fault A proto-mylonite, drillhole U2340, 19.2m. X-polars.

Plate 4.9 Fault Z proto-mylonite with cross-cutting Fe-chlorite (hydrothermal chlorite as opposed to contact metasomatic Mg-chlorite) vein (cl). Drillhole U2736, 299.8m. X-polars.

Plate 4.10 Hydrothermal reaction front in dolomite in drillhole U2801, 310m, 66400m N, 1350m RL. Stylolites (st1) are probably related to early diagenesis. These are crosscut by carbonate veins (cv) which are in turn crosscut by the chloritic stylolite (st2) which accompanies the reaction front. A fringe of pyrrhotite (po) and fine tremolite needles preceeds the main reaction front.

earlier ductile fabric in Fault Z.

Plate 4.10 offers further evidence of the timing of mineralisation with respect to deformation. A hydrothermal reaction front and accompanying chloritic stylolite crosscut carbonate veins which, in turn, crosscut early diagenetic(?) stylolites. The carbonate veins are unlikely to have formed during early D3 ductile deformation, and may have been associated with brittle deformation closely preceeding hydrothermal activity or with earlier D2 or Cambro-Ordovician (Corbett and Lees, 1987) deformation events.

The above evidence points to a significant time lag between syn-intrusive ductile deformation and the brittle reactivation which initiated hydrothermal activity.

4.10 SUMMARY ...

Modelling of the spatial distribution of tin grades, sulphur and oxygen isotopes and homogenisation temperatures from primary fluid inclusions along the Federal-Bassett Fault defines a radial pattern of hydrothermal palaeoflow about the Pine Hill Granite. Local upflow zones correspond to dilational regions within the Federal-Bassett Fault system.

North of 66400m N a broad concave-east fold in the North Bassett Fault formed where strain was transferred onto Faults A and Z. Dilation of the North Bassett Fault in the axis of the fold served to focus hydrothermal fluid flow into the Rendeep and North Bassett areas (Fig. 4.8). In the Rendeep area dilation of the North Bassett Fault above the

Rendeep Graben/Syncline occurred during D3 dip-slip deformation and became a major focus for hydrothermal fluids, resulting in widespread mineralisation of dolomites of the adjacent Renison Mine Sequence.

D3 strike-slip deformation served to further focus hydrothermal fluid flow by maintaining permeability on the North Bassett Fault and by creating dilational sites in the hinge zones of weak dextral kink folds in the Renison Mine Sequence, interstitial to Fauit A and the North Bassett Fault.

Hydrothermal activity commenced in conjunction with brittle D3 dip-slip reactivations on the Federal-Bassett Fault (Kitto, 1994). Syn-intrusive ductile deformation, associated with boron metasomatism, (Plates 3.8, 3.9, 3.26, 4.8 & 4.9) predated the brittle reactivations. The transition from ductile to brittle deformation styles occurred in response to the cooling of the Pine Hill Granite. The granite developed a crystalline outer shell prior to brittle failure and the release of magmatic hydrothermal fluids.

Laboratory experiments by Heard (1960) and Handin & Hager (1957) indicate that ductile behaviour in dolomite could be anticipated for the range of temperatures and lithostatic pressures estimated for the Rendeep area. The transition to ductile behaviour in dolomite is thought to be a limiting factor governing the development of replacement mineralisation at distances closer than 400m to the Pine Hill Granite.

The exploration significance of the modeling of hydrothermal fluid flow and the brittle-ductile transition in dolomites is discussed in Chapter 5.

CHAPTER 5: EXPLORATION SIGNIFICANCE

5.1 INTRODUCTION ...

In Chapter 4 the relationship between dilational structures and the flow paths of hydrothermal fluids was established by the modelling of tin grades, oxygen and sulphur isotope, and fluid inclusion studies. The brittle-ductile transition in dolomite was proposed as a physical constraint on the formation of widespread replacement mineralisation close to the Pine Hill Granite. In this chapter, knowledge of the relationship between dilational structures and hydrothermal fluid flow, and of the inferred brittle-ductile transition in dolomites is used: (1) to predict regions suitable for economic tin mineralisation outside the current Rendeep resource boundaries, and (2) as an exploration model for replacement mineralisation around the Pine Hill Granite.

5.2 GRANITE MORPHOLOGY ...

The relationship between syn-intrusive faulting and the morphology of the Pine Hill Granite was demonstrated in Chapter 3, Section 3.5.1.1 & 3.5.1.2; Figures 3.1, 3.7 & 3.8. Syn-intrusive faulting is strongly developed above the region of maximum curvature in the Pine Hill Granite surface. Gravity surveys represent the best method for defining the granite morphology on a regional scale in order to predict the location of faults that may have been conduits for mineralising fluids.

5.3 FAULTING ...

Brittle reactivations on major faults were responsible for hydrothermal fluid release rather than early D3 ductile to semi-ductile deformation (Chapter 3, Sections 3.5.1.2, 3.5.2.5 and 3.6.3; Chapter 4, Section 4.9). Early D3 deformation during granite emplacement resulted in the subvertical extension of the eastern limb of the D2 Renison Bell Anticline producing a failed monoclinal fold. The Federal-Bassett Fault reactivated as a brittle structure late in the intrusive history of the Pine Hill Granite, penetrating and displacing the granite's crystallised outer shell and releasing hydrothermal fluids. Brittle reactivations took place above the region of maximum curvature in the Pine Hill Granite surface. Consequently, mineralisation in the Federal-Bassett Fault on a broad scale is likely to be radially zoned about this region, rather than evenly distributed along the length of the Federal-Bassett Fault / Monocline.

Continual brittle reactivations were essential to maintain high permeability in the mineralising faults. The combination of D3 dip-slip reactivations and later D3 strike-slip reactivations served to dilate the Federal-Bassett Fault (Kitto, 1994). In the Rendeep area, strain transferral from the North Bassett Fault onto Faults A and Z produced a concave-east fold in the North Bassett Fault which became a major focus for hydrothermal flow (Chapter 4, Section 4.7.1). A jog in the Federal-Bassett Fault between the projected contacts with "Shears L and P", which has a similar axial trend and plunge, hosts the Federal orebody (Kitto, 1994). Further exploration, both north and south on the Federal-Bassett Fault should seek inflections in the structure contours which may be the expression of similar dilational structures.

5.4 MODELLING OF HYDROTHERMAL FLUID FLOW ...

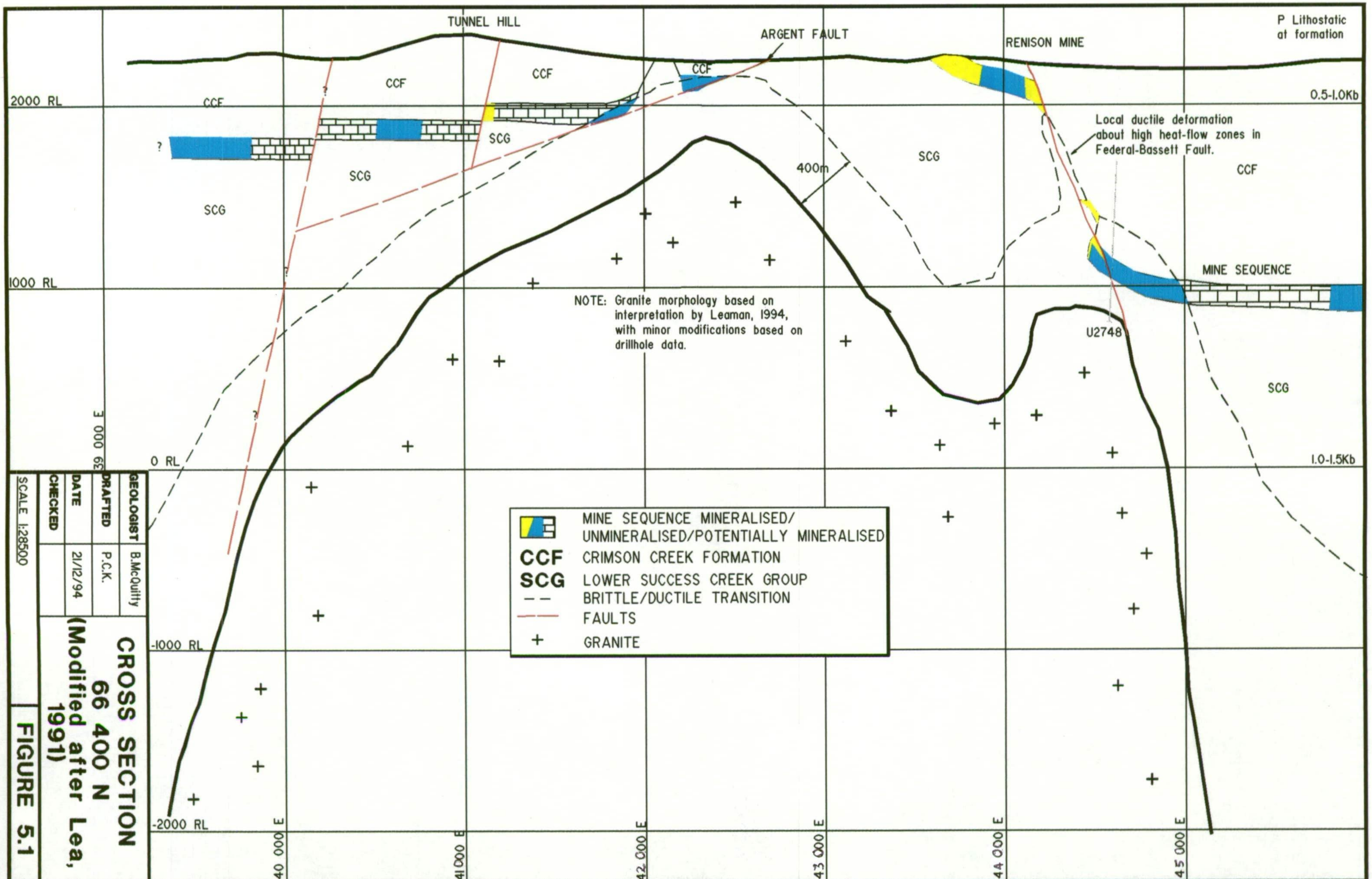
The use of oxygen and sulphur isotopes for modelling the pattern of hydrothermal fluid flow was successful in the Rendeep area. Isotopically lighter regions, interpreted as fluid upflow zones, match closely the known dilational regions on the North Bassett Fault (Chapter 4, Sections 4.4 & 4.5). Oxygen isotopes give the best definition of structural controls to hydrothermal fluid flow and also provide an apparent range of $\delta^{18}O_{qz}$ values (14-16‰) in the Federal-Bassett Fault for which stratabound mineralisation can be expected in adjacent Renison Mine Sequence carbonates. Relatively low $\delta^{18}O_{qz}$ values in the North Bassett Fault in drillholes S1192 and S343 indicate that the hydrothermal fluid upflow zone in the Rendeep area persists for several hundred metres north of the currently defined orebodies (Fig. 4.5). An intersection of 6m x 0.6% Sn in drillhole S343 (Fig. 4.5) is further indication of the potential for northward extensions to Rendeep mineralisation. At the southern end of the Rendeep area $\delta^{18}O_{qz}$ values from the North Bassett Fault fall below 14‰ (Fig. 4.5), which is interpreted as indicating less favourable conditions for stratabound replacement-style mineralisation (although this relationship has not been firmly established). The tin grade distribution is inconclusive; grades in the No. 1 Horizon improve towards the granite (Fig. 4.3), whereas the grades in the Zeehan orebody (No. 2 Horizon) decrease near its southern margin (Fig. 4.4). There is, however, a tendency for replacement mineralisation to be more localised about feeder faults towards the southern end of the Rendeep area.

Fluid inclusion studies should theoretically be the best means of modelling hydrothermal fluid flow patterns, however, the industrial application of this technique at Renison is limited by practical difficulties (listed in Chapter 4, Section 4.6.1) and time constraints. Oxygen isotopes from hydrothermal quartz are recommended for future modelling of hydrothermal palaeoflow paths.

5.5 BRITTLE-DUCTILE TRANSITION IN DOLOMITE ...

In Chapter 4, Section 4.8.3, it was suggested that the transition from brittle to ductile behaviour in dolomite may restrict the development of stratabound replacement-style mineralisation at distances closer than 400m from the Pine Hill Granite. Figure 5.1 shows a cross section through the Pine Hill Granite at 66400m N, corresponding to the southern end of the Rendeep area. The Renison Mine Sequence has been subdivided into areas: (1) known to host replacement-style mineralisation, (2) known and inferred to be unmineralised and, (3) potentially mineralised. Beyond a 400m radial distance from the Pine Hill Granite the dolomite horizons of the Renison Mine Sequence are considered to be susceptible to replacement provided that they have access to mineralising fluids. The location of drillhole U2748 which provides a control on the granite surface at the southern end of the Rendeep area is shown in Figure 5.1. Stratabound mineralisation was weakly developed in this drillhole.

Further drilling of the Renison Mine Sequence/North Bassett Fault contact towards the Pine Hill Granite is recommended to test whether stratabound replacement-style mineralisation can occur at distances closer than 400m from the Pine Hill Granite. The



CROSS SECTION 66 400 N (Modified after Lea, 1991)

FIGURE 5.1

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results can be used to constrain target selection on other tin exploration prospects.

5.6 FUTURE EXPLORATION TARGETS ...

A list of potential exploration targets within the Rendeep area are summarised below (refer to Plates 5.1 & 5.2 for target location).

1) Extensions to the Waratah orebody south of 66375m N (No. 1 Horizon in the hangingwall of the North Bassett Fault).

2) The Renison Mine Sequence in the North Bassett Fault hangingwall, down the plunge of its contact with the North Bassett Faullt towards the Renison Mine Sequence/Pine Hill Granite contact.

3) The contact of the No. 1 Horizon with the North Bassett Fault, north of section 67000m N along the trend defined by low $\delta^{18}O_{qz}$ values (Section 5.3).

4) The down-plunge extensions to the Renison Mine Sequence in the footwall of the North Bassett Fault.

Targets 1,2 and 4 involve drilling the Renison Mine Sequence closer to the Pine Hill Granite than has been previously attempted at the Renison mine and will test the upper limits of temperatures and pressures at which stratabound mineralisation can occur.

Plate 5.1 3-Dimensional model, looking west, with drillholes displayed. Untested exploration targets include: (1) No. 1 Horizon in hangingwall of North Bassett Fault (extension south of Waratah orebody), (2) Contact of North Bassett Fault with hangingwall Mine Sequence, down-plunge to south. (3) Contact of No. 1 Horizon with North Bassett Fault, northern extention.

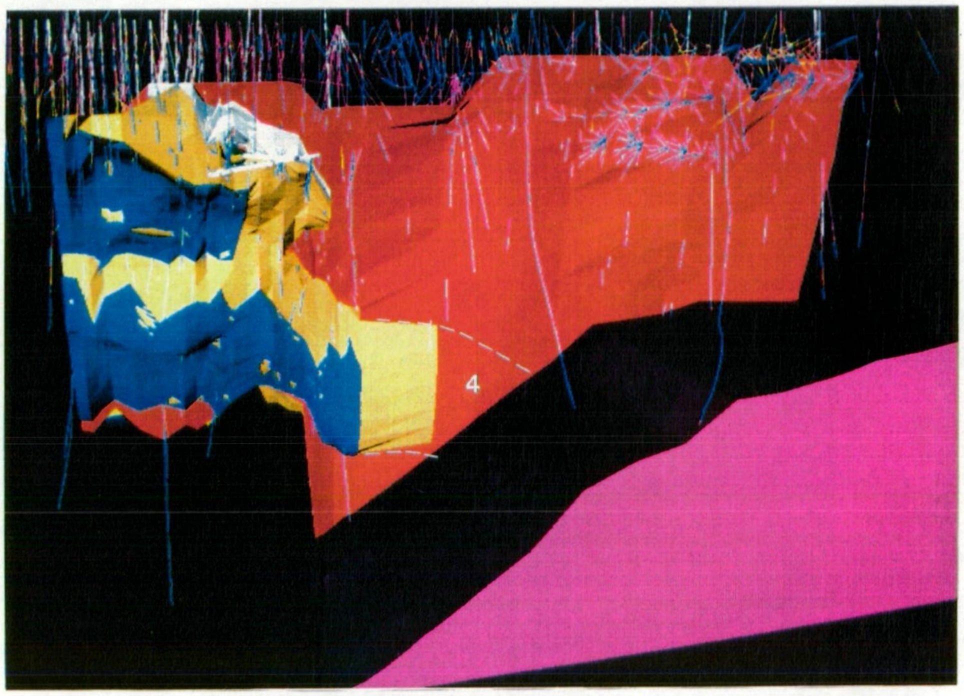

Plate 5.2 3-Dimensional model, looking east-southeast, with drillholes displayed. Exploration target (4) is Mine Sequence in the footwall of the North Bassett Fault, southern extension towards the granite.

CHAPTER 6: CONCLUSIONS

A structural interpretation of the Rendeep area has been completed from correlations, between drillholes, of stratigraphic units of the Renison Mine Sequence and lower Crimson Creek Formation. A confident interpretation of the gross structure was possible at the existing drilling pattern due to the high lateral continuity of most of the stratigraphic units and to the understanding of the sedimentary depositional environment (Chapter 2; Morrison, 1982 & 1993).

The structural history of the Rendeep area has been compiled, based on structural interpretations, thin section evidence and limited underground mapping. The timing of mineralisation in relation to deformational events has been established from thin section evidence and interpretation of the temporal and spatial relationship of the Federal-Bassett Fault to the Pine Hill Granite intrusion. The deformational events recognised by Kitto (1994) for the remainder of the Renison deposit were also recognised in the Rendeep area with minor changes to the deformational style and principle stress directions resulting from the relative proximity to, and the morphology of, the underlying Pine Hill Granite.

The structural development of the Rendeep area is dominated by Devonian D3 deformation associated with the forceful emplacement of the Pine Hill Granite into the axial region of the Devonian D2 Renison Bell Anticline. D3 dip-slip deformation produced a throw of 770m on the North Bassett Structure along the failed eastern limb of the Renison Bell Anticline (Fig. 3.2). Sub-vertical extension of the Renison Mine Sequence occurred through a combination of brittle faulting, flexural slip and ductile deformational processes, with ductile deformation processes predominant nearer the Pine Hill Granite. The North Bassett Fault formed by layer-parallel extension in the strongly layered Renison Mine Sequence close to its contact with the more massive overlying Crimson Creek Formation. Faults A and Z formed as sub-vertical extensional faults in response to the sub-vertical principle stress direction (Fig. 3.8). A broad, open concave-east fold in the Renison Mine Sequence and North Bassett Fault north of 66400m N developed in response to strain transferral from the North Bassett Fault onto Faults A and Z (Figs. 3.4 & 3.5). The axial region, which plunges in the inferred dip-slip direction of ~70° S, became a major upflow zone for hydrothermal fluid flow during D3 brittle reactivations (Fig. 4.8). D3 dip-slip deformation also produced the Rendeep Graben/Syncline by rotation of the Renison Mine Sequence from a 30° dip in the hangingwall of the North Bassett Fault to sub-vertical, draped along Fault Z, and by initiating normal movement on the Csar Fault (Fig. 3.2). Strain transferral from the North Bassett Fault to Fault Z resulted in dilation of the North Bassett Fault above the Rendeep Graben/Syncline and served to focus hydrothermal fluid flow (Figs. 4.9 & 4.10). Uncoupling of bedding planes during D3 folding and flexural slip assisted hydrothermal fluid ingress, resulting in widespread replacement of the adjacent Renison Mine Sequence dolomites. Brittle dip-slip reactivation of the Federal-Bassett Fault occurred late in the D3 deformational event after a period of cooling and crystallisation of the outer shell of the Pine Hill Granite.

D3 dextral wrench deformation accompanied the decay of the radial stress field around the Pine Hill Granite and a return to the regional Tabberabberan stress field (Kitto, 1994). In the Rendeep area, D3 dextral wrench deformation produced strike-slip reactivations on the North Bassett Fault and Faults A & Z(?) and may have initiated the Batch Fault. Locking of strike-slip movement on the North Bassett Fault near 66400m N resulted in local north-south shortening of the Renison Mine Sequence, producing a weak dextral kink fold between Fault A and the North Bassett Fault, the hinge zone of which became the focus of hydrothermal fluid flow (Figs.3.15 & 4.11).

Deformational textures display a transition from brittle to ductile features approacing the Pine Hill Granite (e.g. Plates 3.13-3.15). The elevated temperatures (and possibly pressures) in the contact metamorphic aureole are considered responsible for the observed localisation of replacement mineralisation about major feeder faults at the southern end of the Rendeep area, through their influence on the brittle/ductile transition in dolomites of the Renison Mine Sequence. Ductile behaviour is thought to inhibit the growth of macrofaults and microfractures in dolomite, thereby restricting fluid/rock interaction. A radial distance of 400m from the Pine Hill Granite is proposed as a theoretical limit to extensive stratabound replacement-style mineralisation. Drilling of the Renison Mine Sequence/North Bassett Fault contact closer than 400m from the Pine Hill Granite is recommended to test this relationship; the results can then be used as a guide for further exploration.

The use of oxygen and sulphur isotopes for modelling hydrothermal fluid flow paths has been successful in the Rendeep area and has helped to define areas of further exploration potential (e.g. to the north of the Rendeep Graben/Syncline). Dilational structures have been identified and the location of further dilational structures may be predicted through the combination of stable isotopic studies and structural interpretation.

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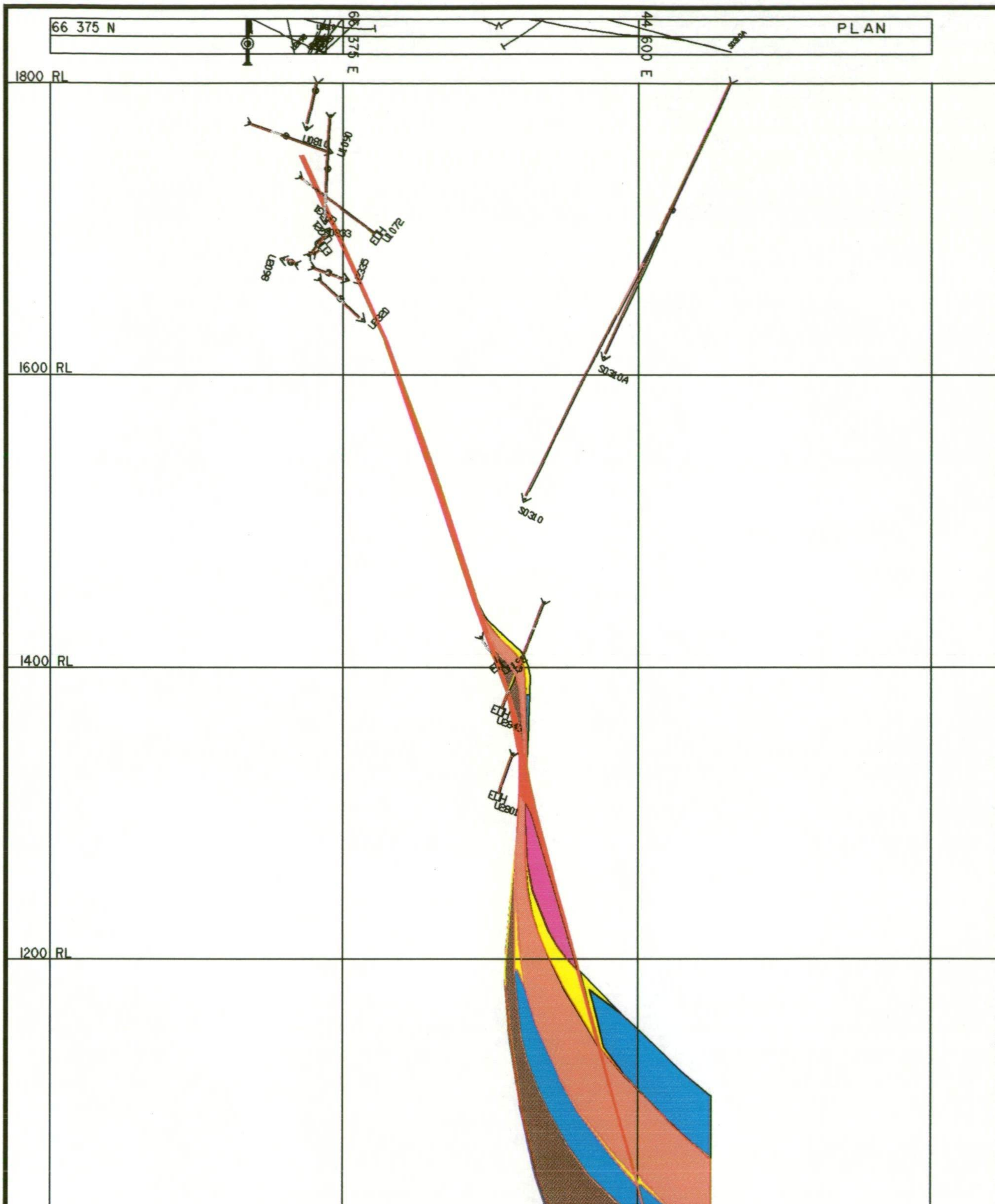
APPENDIX 1: RENDEEP CROSS-SECTIONS



LEGEND

- Fault mineralisation
- Stratabound mineralisation
- Dolomite
- Renison Bell Member
- Dreadnought Hill Member
- Red Rock Member

GEOLOGIST	B.McQuitty
DRAFTED	S.F.M.
DATE	03/01/95
CHECKED	

RENDEEP SECTION 66 375 N

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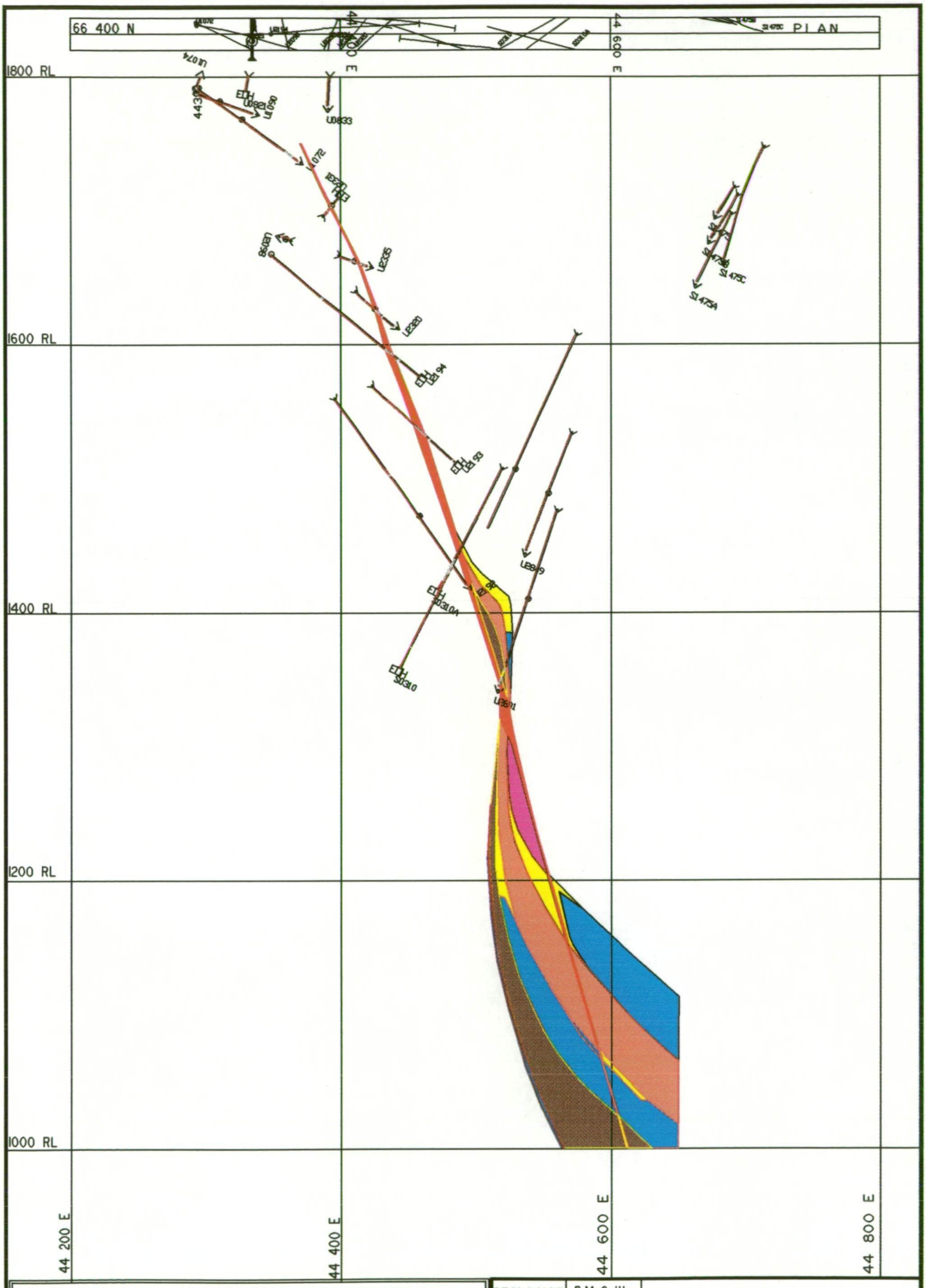

LEGEND

Fault mineralisation	Renison Bell Member
Stratabound mineralisation	Dreadnought Hill Member
Dolomite	Red Rock Member

GEOLOGIST	B.McQuitty	**RENDEEP SECTION 66 400 N**
DRAFTED	S.F.M.	
DATE	03/01/94	
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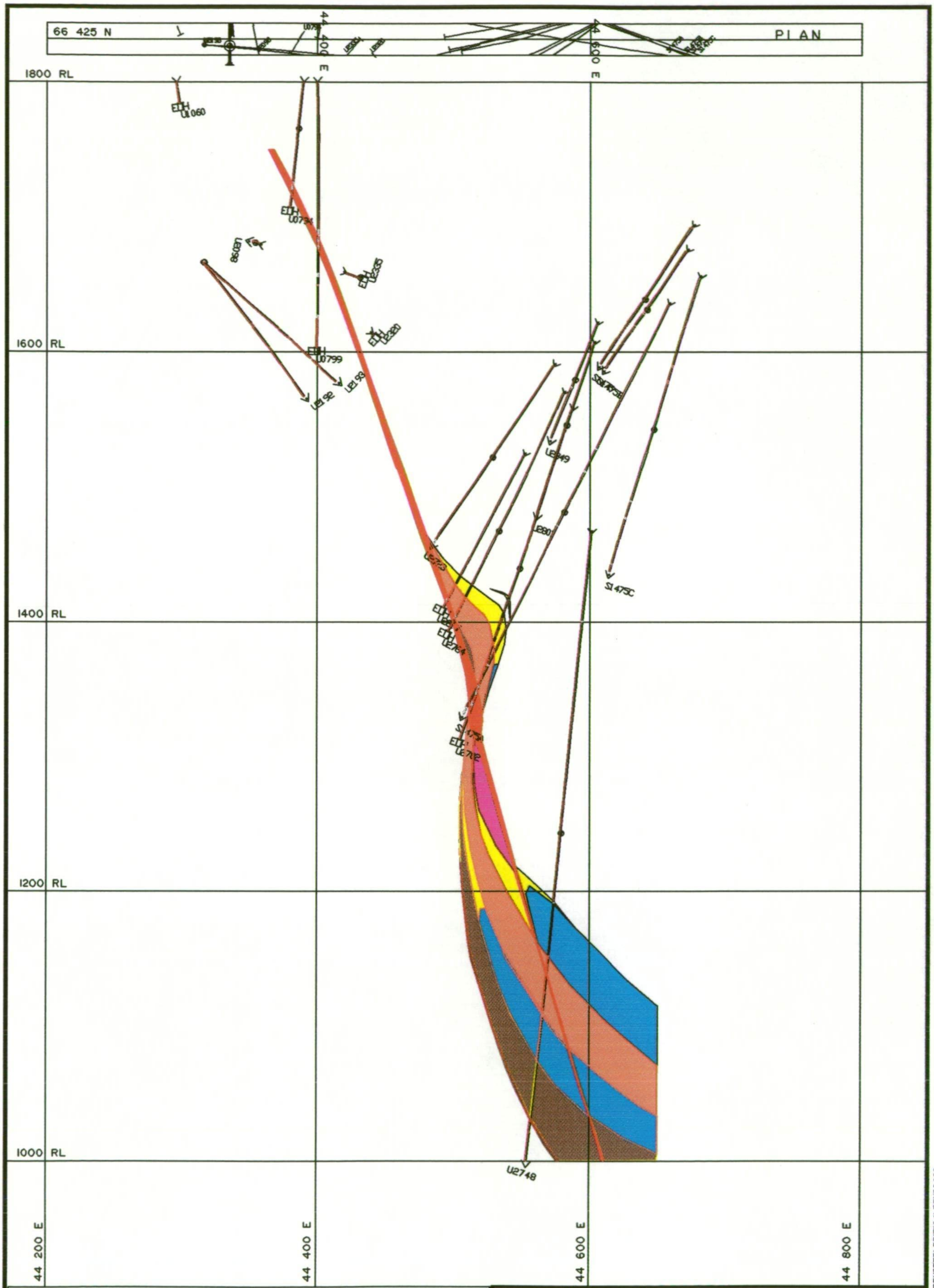

LEGEND

Fault mineralisation	Renison Bell Member
Stratabound mineralisation	Dreadnought Hill Member
Dolomite	Red Rock Member

GEOLOGIST	B.McQuitty
DRAFTED	S.F.M.
DATE	04/01/95
CHECKED	

SCALE 1:4000

RENDEEP SECTION 66425 N

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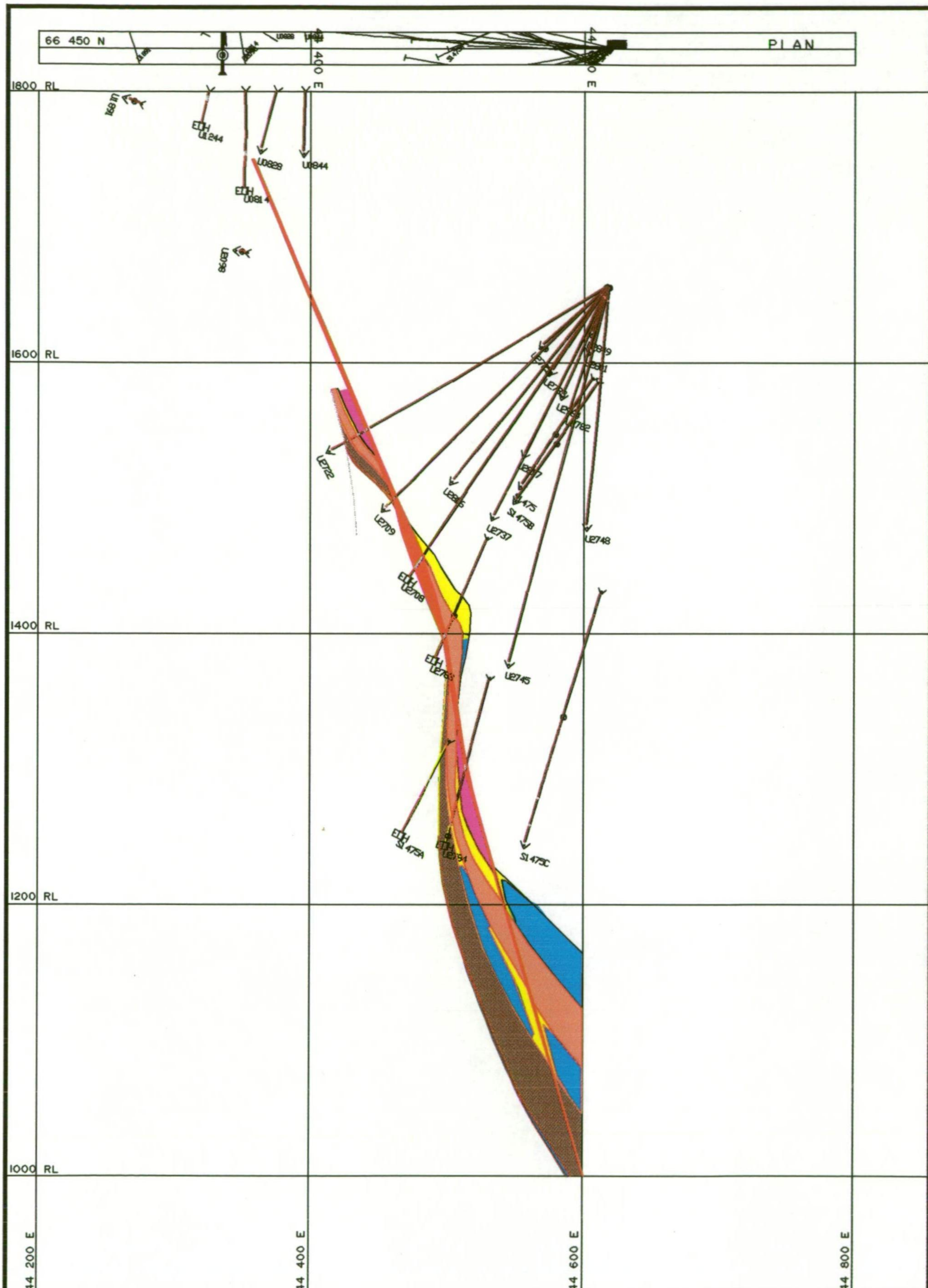

LEGEND

Fault mineralisation	Renison Bell Member
Stratabound mineralisation	Dreadnought Hill Member
Dolomite	Red Rock Member

GEOLOGIST	B.McQuitty
DRAFTED	S.F.M.
DATE	04/01/95
CHECKED	
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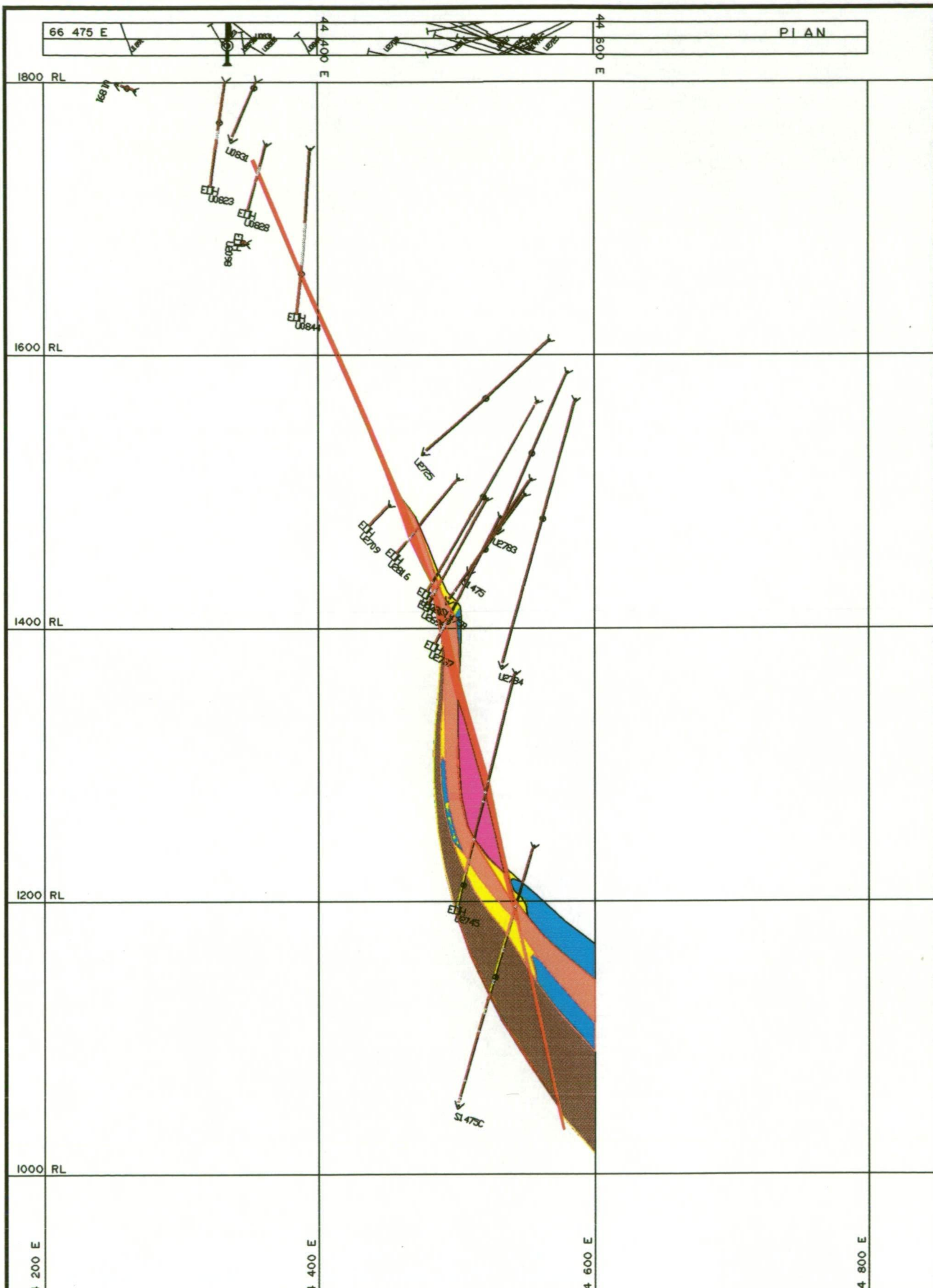
RENDEEP SECTION 66 450 N



LEGEND

Fault mineralisation	Renison Bell Member
Stratabound mineralisation	Dreadnought Hill Member
Dolomite	Red Rock Member

GEOLOGIST	B.McQuitty
DRAFTED	S.F.M.
DATE	05/01/94
CHECKED	

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RENDEEP SECTION 66 475 N

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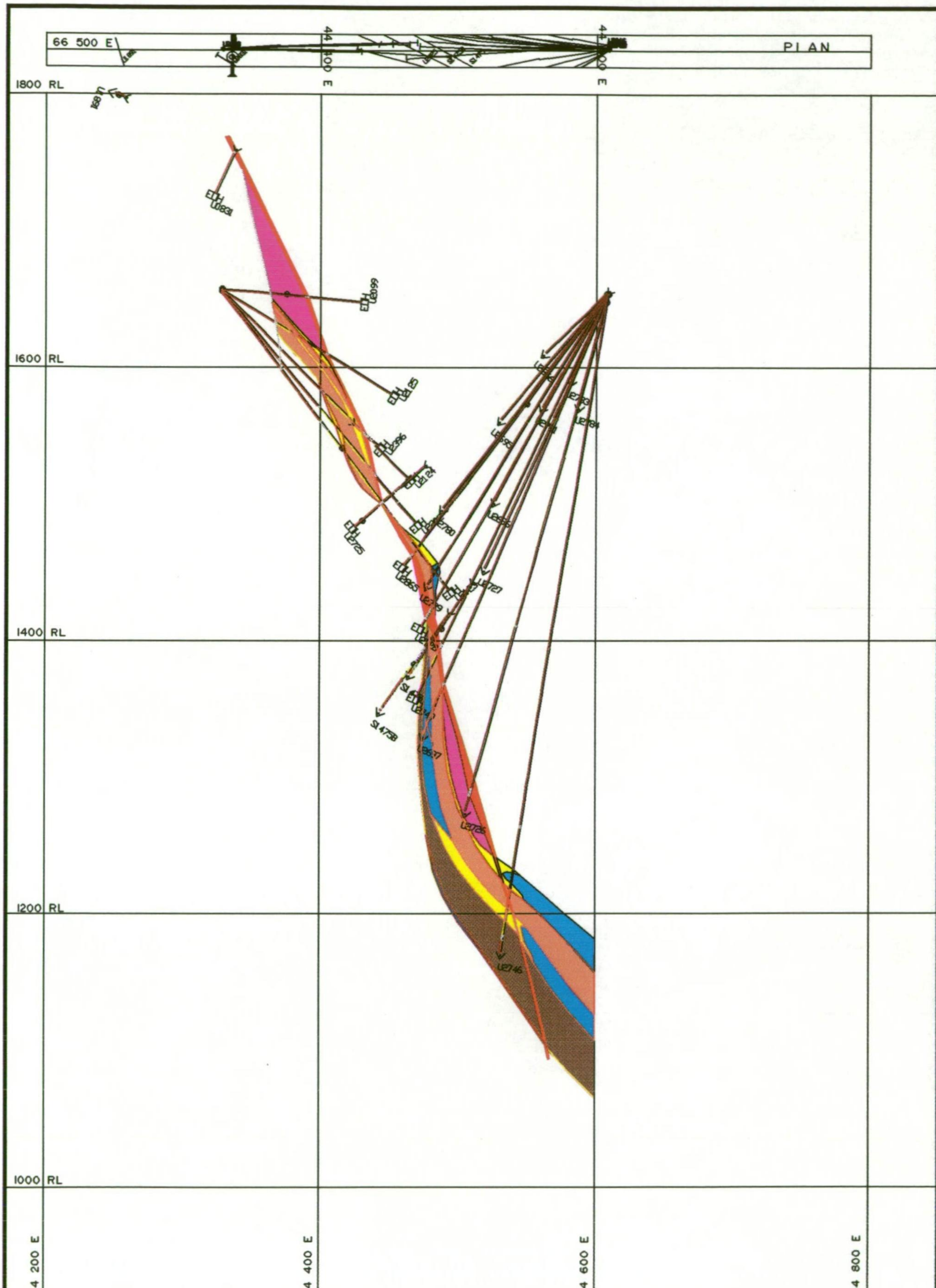

LEGEND

Fault mineralisation	Renison Bell Member
Stratabound mineralisation	Dreadnought Hill Member
Dolomite	Red Rock Member

GEOLOGIST	B.McQuitty
DRAFTED	S.F.M.
DATE	05/01/95
CHECKED	

RENDEEP SECTION 66 500 N

SCALE 1:4000

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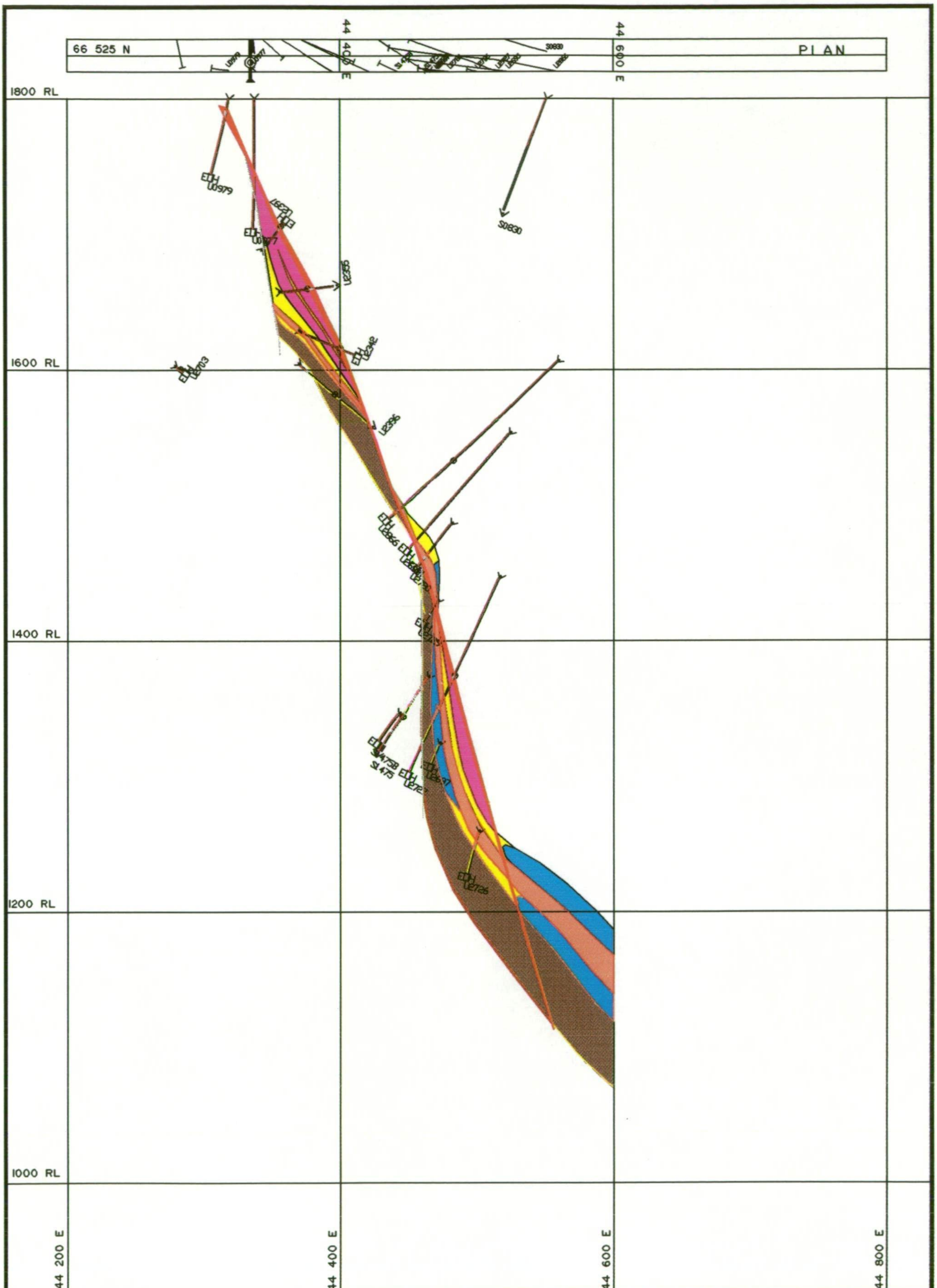

LEGEND

Fault mineralisation	Renison Bell Member
Stratabound mineralisation	Dreadnought Hill Member
Dolomite	Red Rock Member

GEOLOGIST	B.McQuitty
DRAFTED	S.F.M.
DATE	05/01/95
CHECKED	

SCALE 1:4000

RENDEEP SECTION 66 525 N

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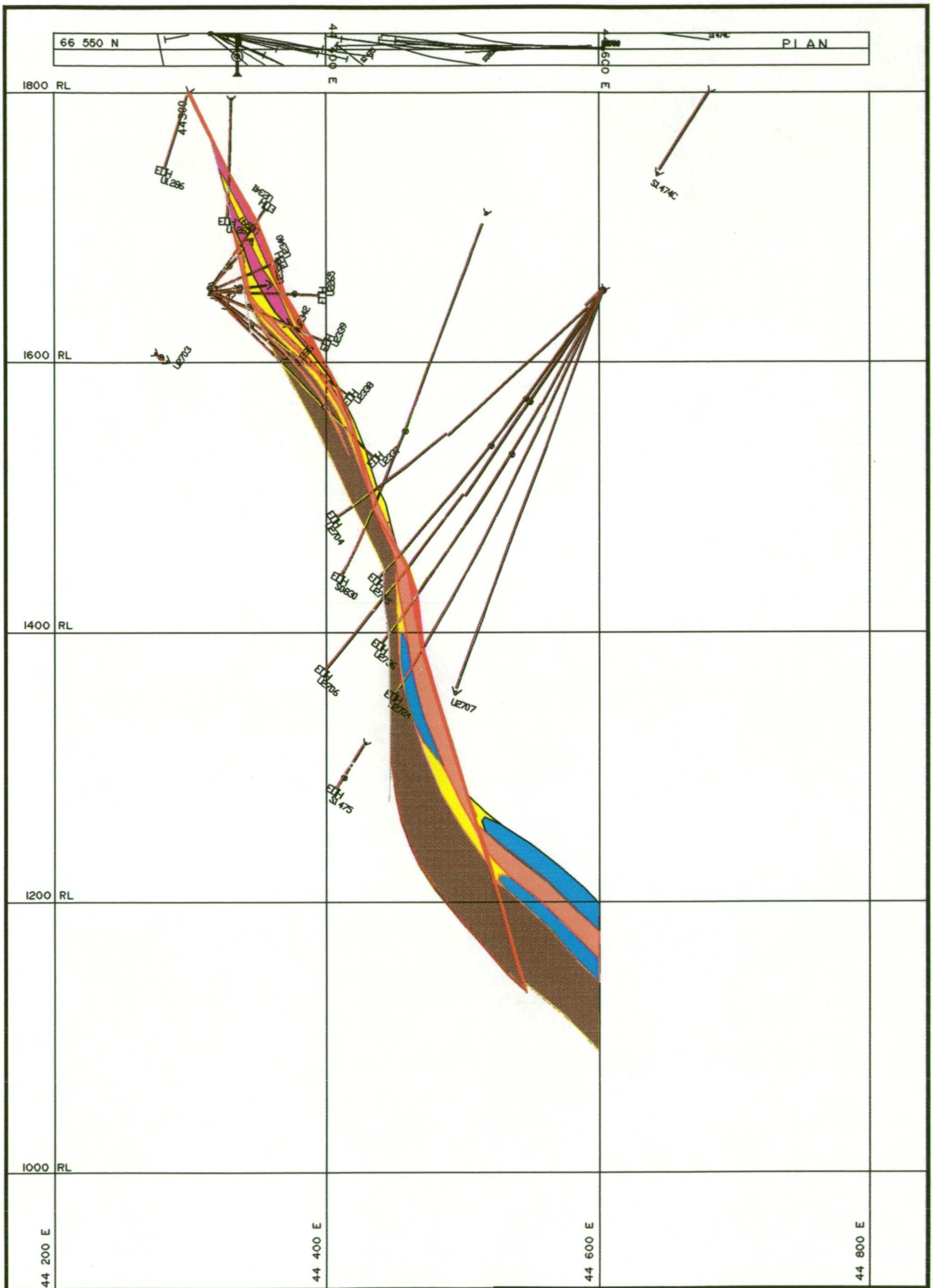

GEOLOGIST	B.McQuitty
DRAFTED	S.F.M.
DATE	05/01/95
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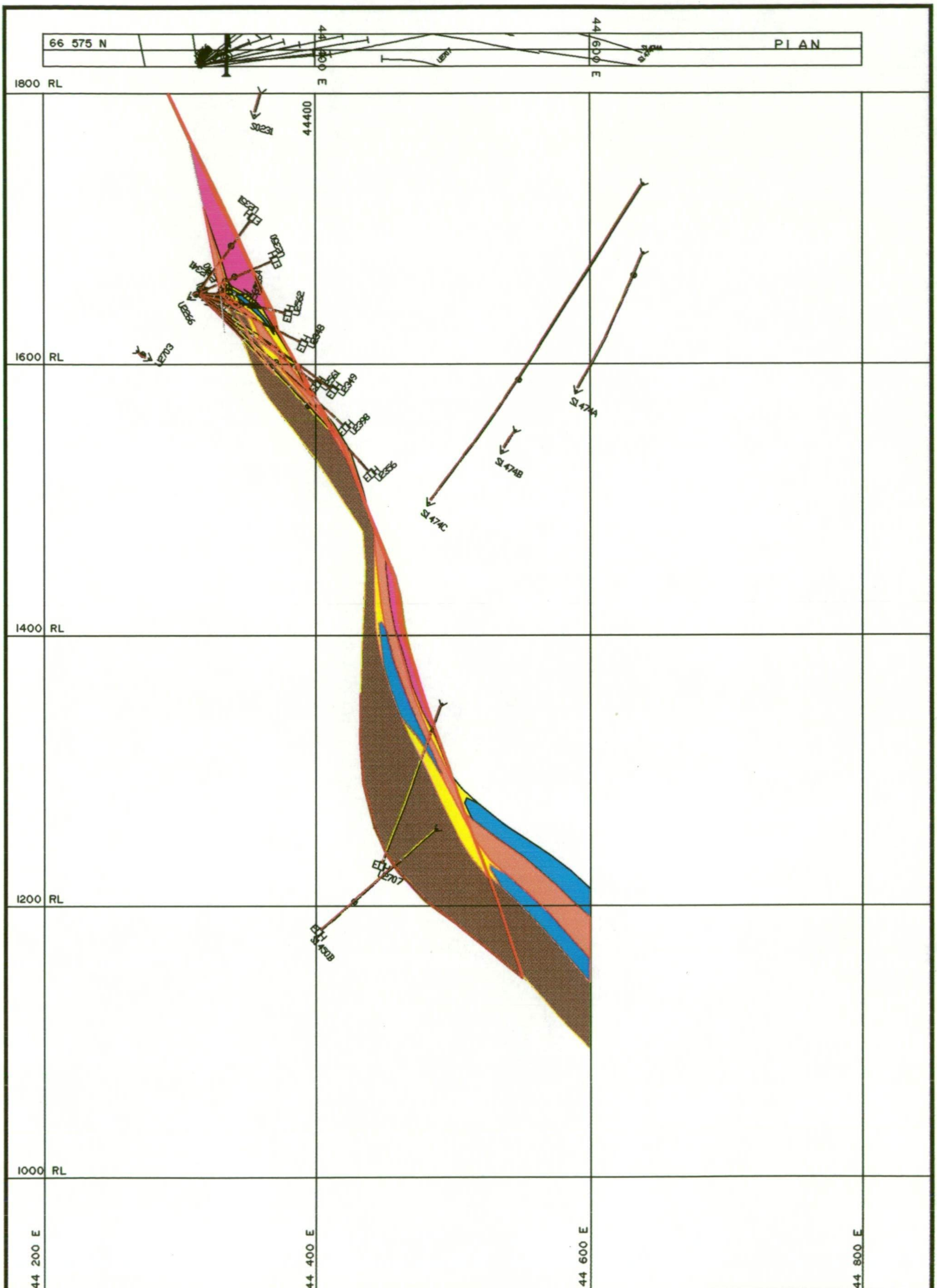

LEGEND

Fault mineralisation	Renison Bell Member
Stratabound mineralisation	Dreadnought Hill Member
Dolomite	Red Rock Member

GEOLOGIST	B.McQuitty
DRAFTED	S.F.M.
DATE	06/01/95
CHECKED	

RENDEEP SECTION 66 575 N

SCALE 1:4000

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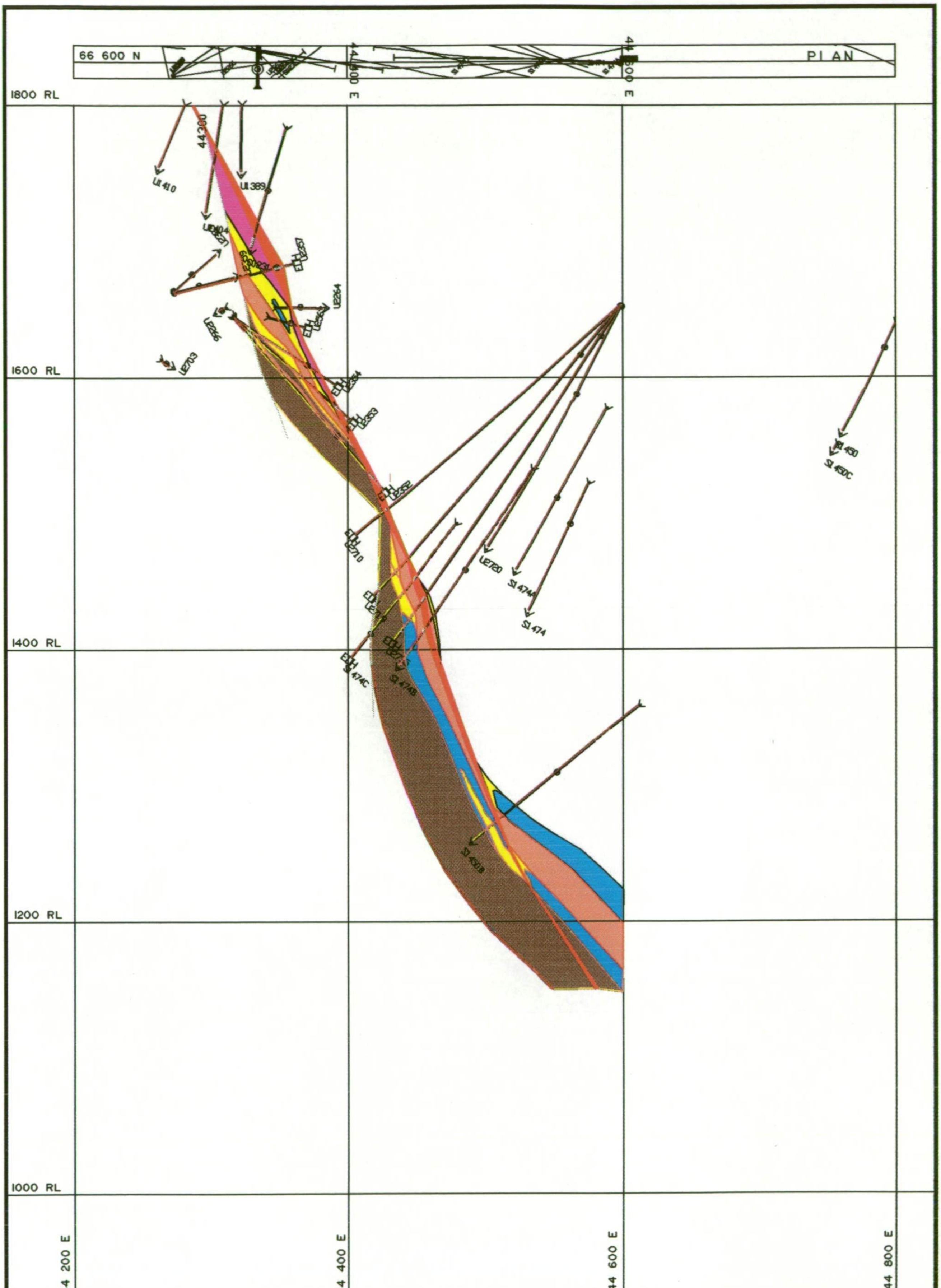

LEGEND

Fault mineralisation	Renison Bell Member
Stratabound mineralisation	Dreadnought Hill Member
Dolomite	Red Rock Member

GEOLOGIST	B.McQuitty	**RENDEEP SECTION 66 600 N**
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DATE	06/01/94	
CHECKED		
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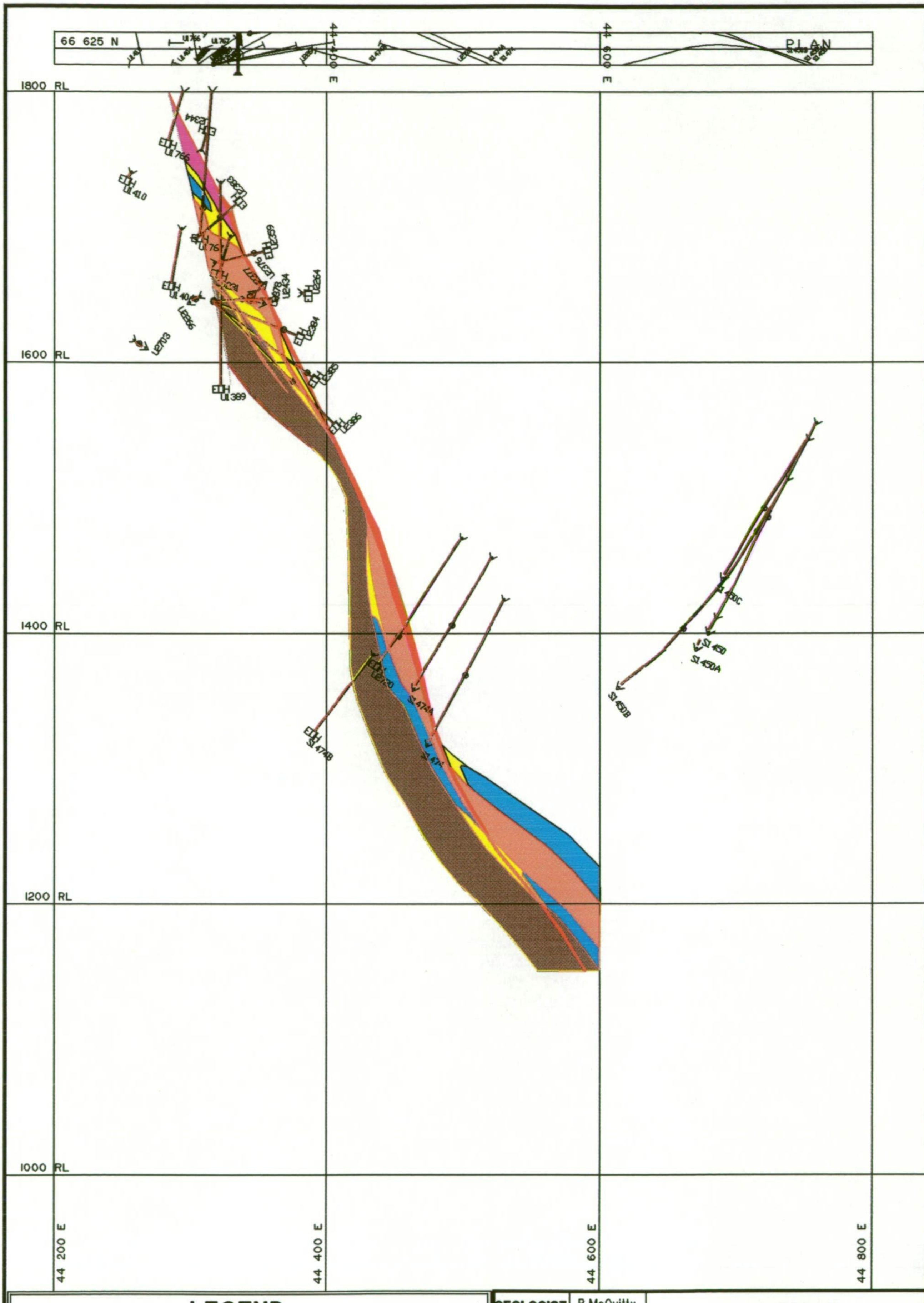

LEGEND

Fault mineralisation	Renison Bell Member
Stratabound mineralisation	Dreadnought Hill Member
Dolomite	Red Rock Member

GEOLOGIST	B.McQuitty	**RENDEEP SECTION 66 625 N**
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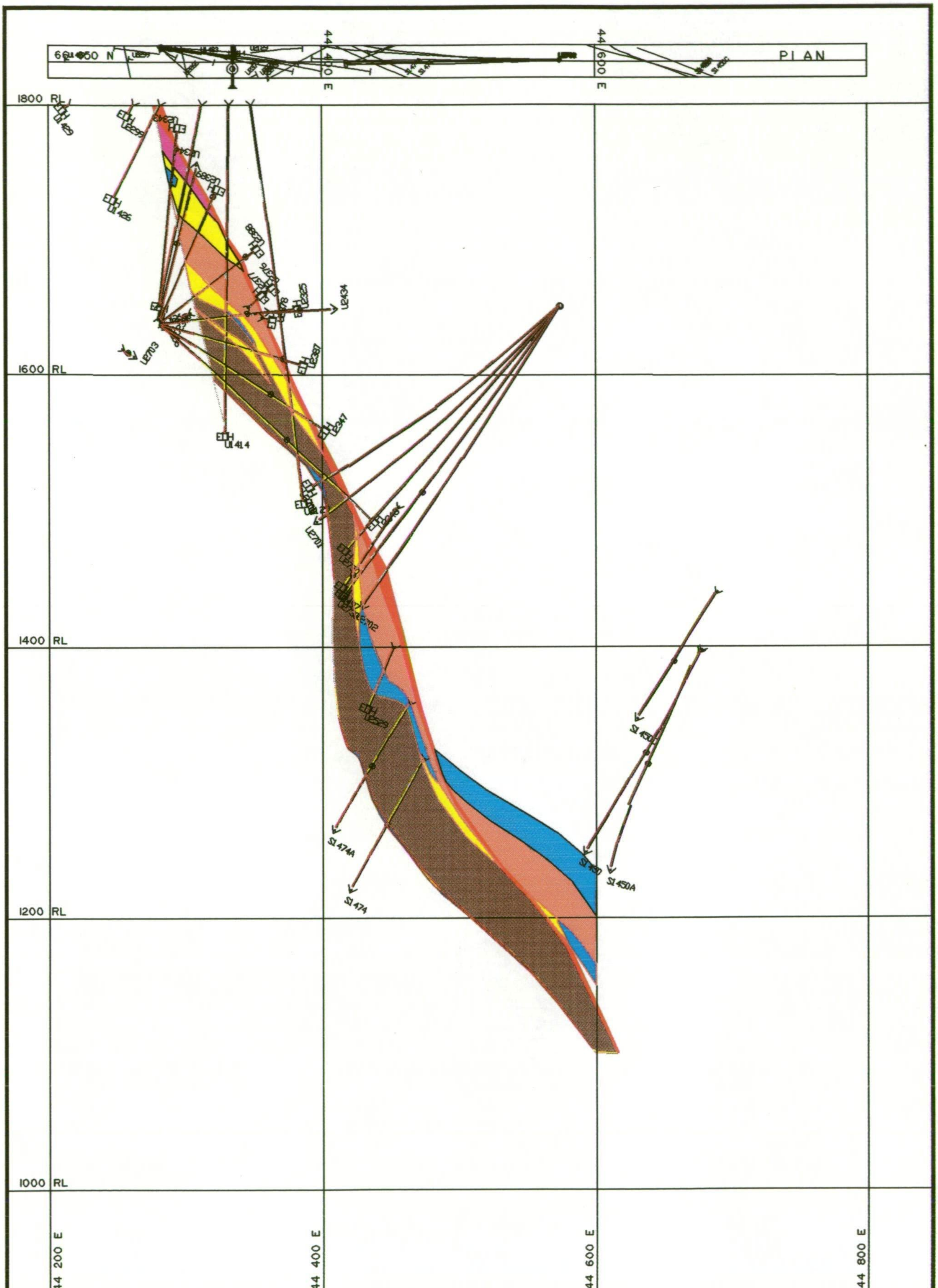

LEGEND

- Fault mineralisation
- Stratabound mineralisation
- Dolomite
- Renison Bell Member
- Dreadnought Hill Member
- Red Rock Member

GEOLOGIST	B.McQuitty
DRAFTED	S.F.M.
DATE	06/01/95
CHECKED	

RENDEEP SECTION 66 650 N

SCALE 1:4000

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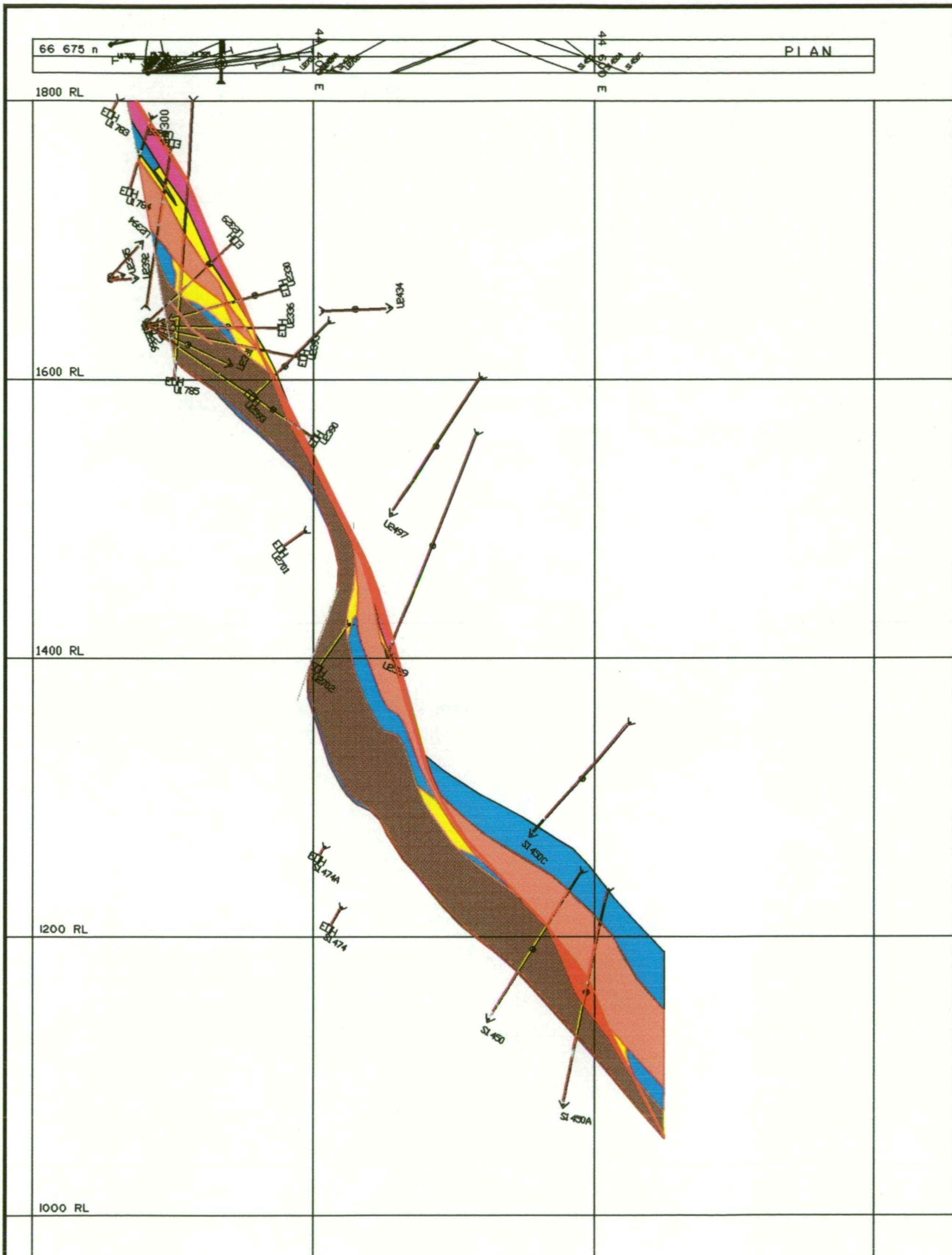

LEGEND

Fault mineralisation	Renison Bell Member
Stratabound mineralisation	Dreadnought Hill Member
Dolomite	Red Rock Member

GEOLOGIST	B.McQuitty
DRAFTED	S.F.M.
DATE	09/01/95
CHECKED	

SCALE 1:4000

RENDEEP SECTION 66 675 N

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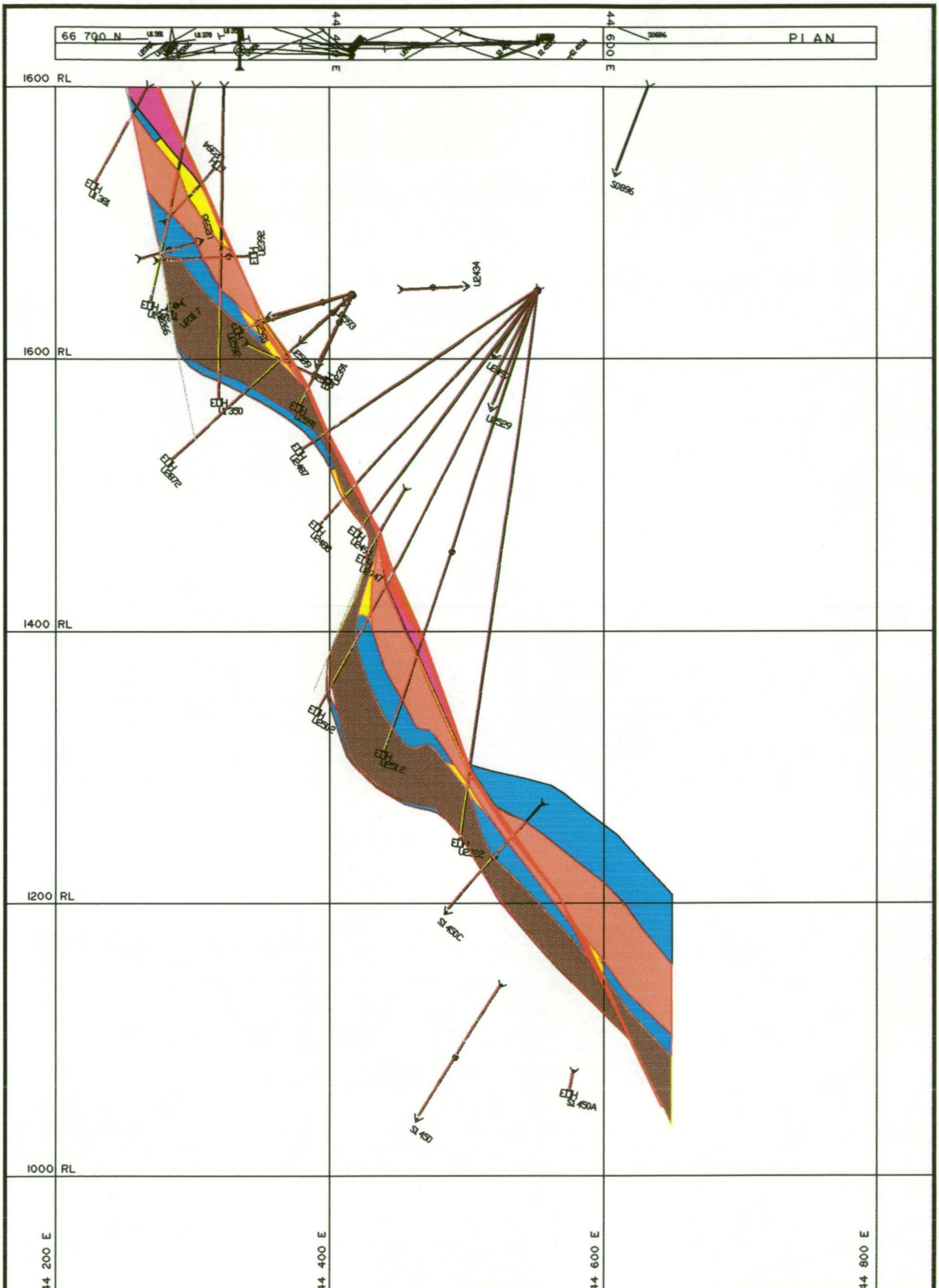

LEGEND

Fault mineralisation	Renison Bell Member
Stratabound mineralisation	Dreadnought Hill Member
Dolomite	Red Rock Member

GEOLOGIST	B.McQuitty
DRAFTED	S.F.M.
DATE	11/1/95
CHECKED	

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RENDEEP SECTION 66 700 N

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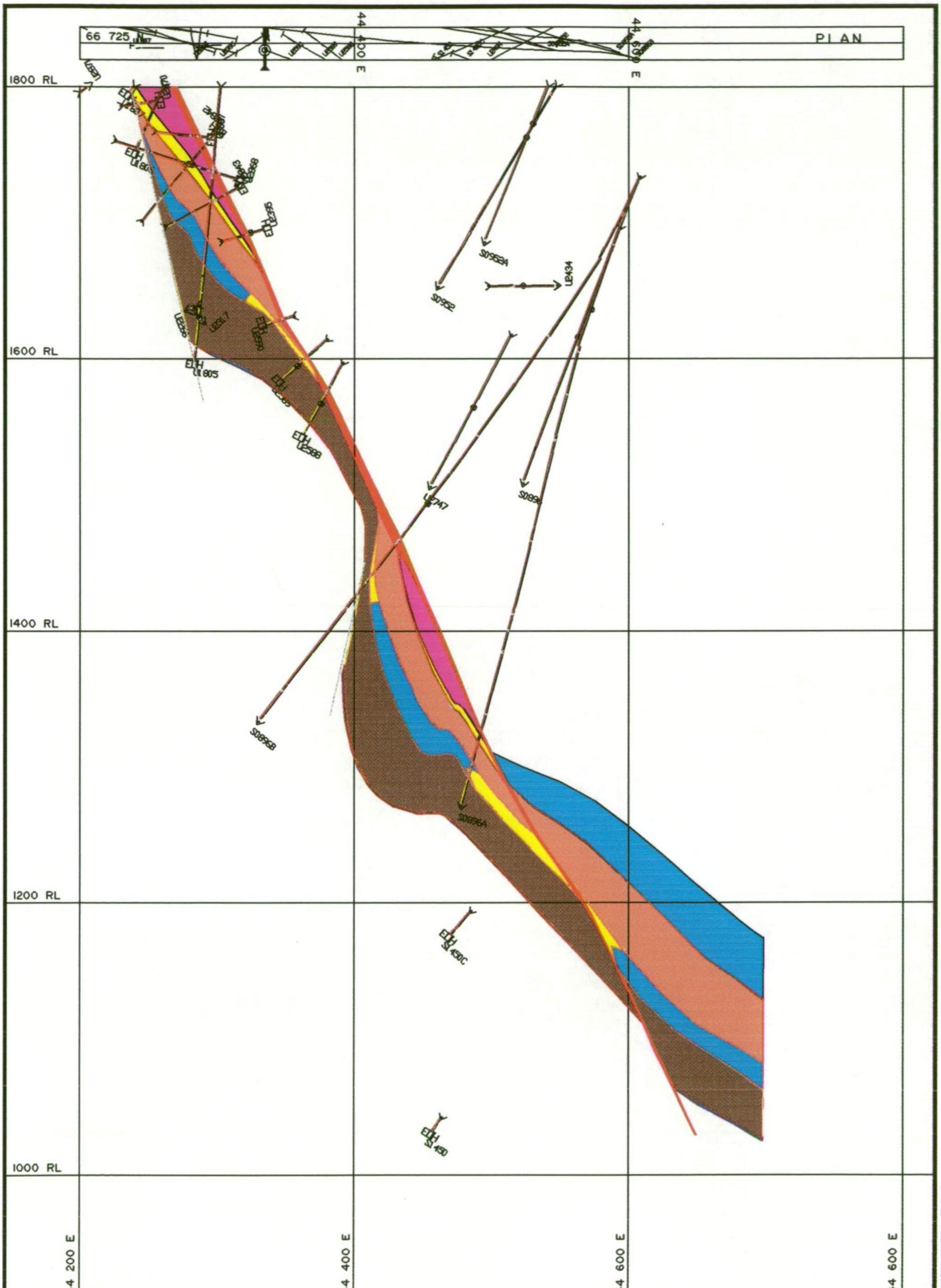

LEGEND

Fault mineralisation	Renison Bell Member
Stratabound mineralisation	Dreadnought Hill Member
Dolomite	Red Rock Member

GEOLOGIST	B.McQuitty
DRAFTED	S.F.M.
DATE	11/01/95
CHECKED	

RENDEEP SECTION 66 725 N

SCALE 1:4000

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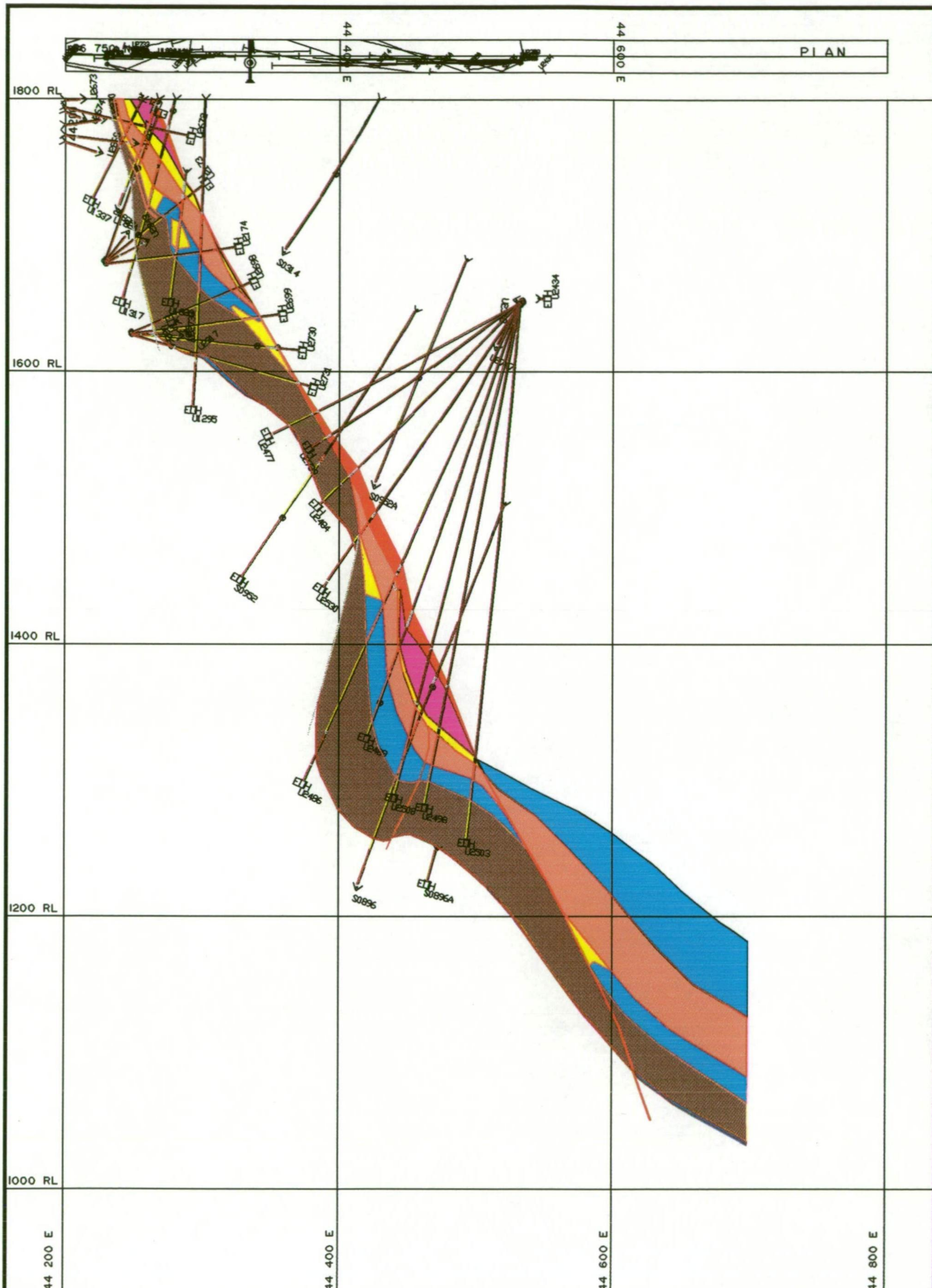

LEGEND

Fault mineralisation	Renison Bell Member
Stratabound mineralisation	Dreadnought Hill Member
Dolomite	Red Rock Member

GEOLOGIST	B.McQuitty
DRAFTED	S.F.M.
DATE	11/01/95
CHECKED	

SCALE 1:4000

RENDEEP SECTION 66 750 N

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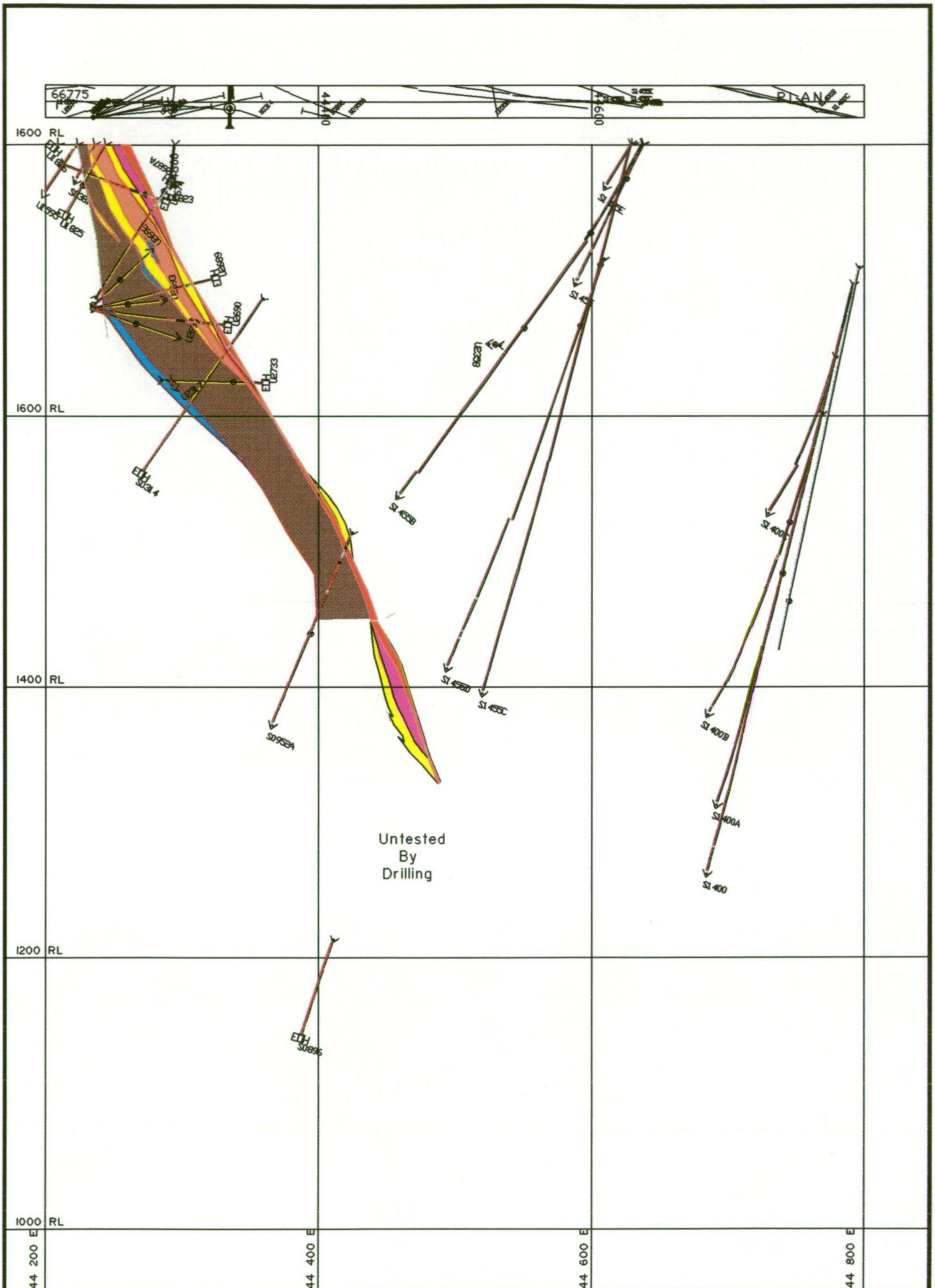

LEGEND

Fault mineralisation	Renison Bell Member
Stratabound mineralisation	Dreadnought Hill Member
Dolomite	Red Rock Member

GEOLOGIST	B.McQuitty	RENDEEP SECTION 66 775 N
DRAFTED	S.F.M.	
DATE	11/01/95	
CHECKED		
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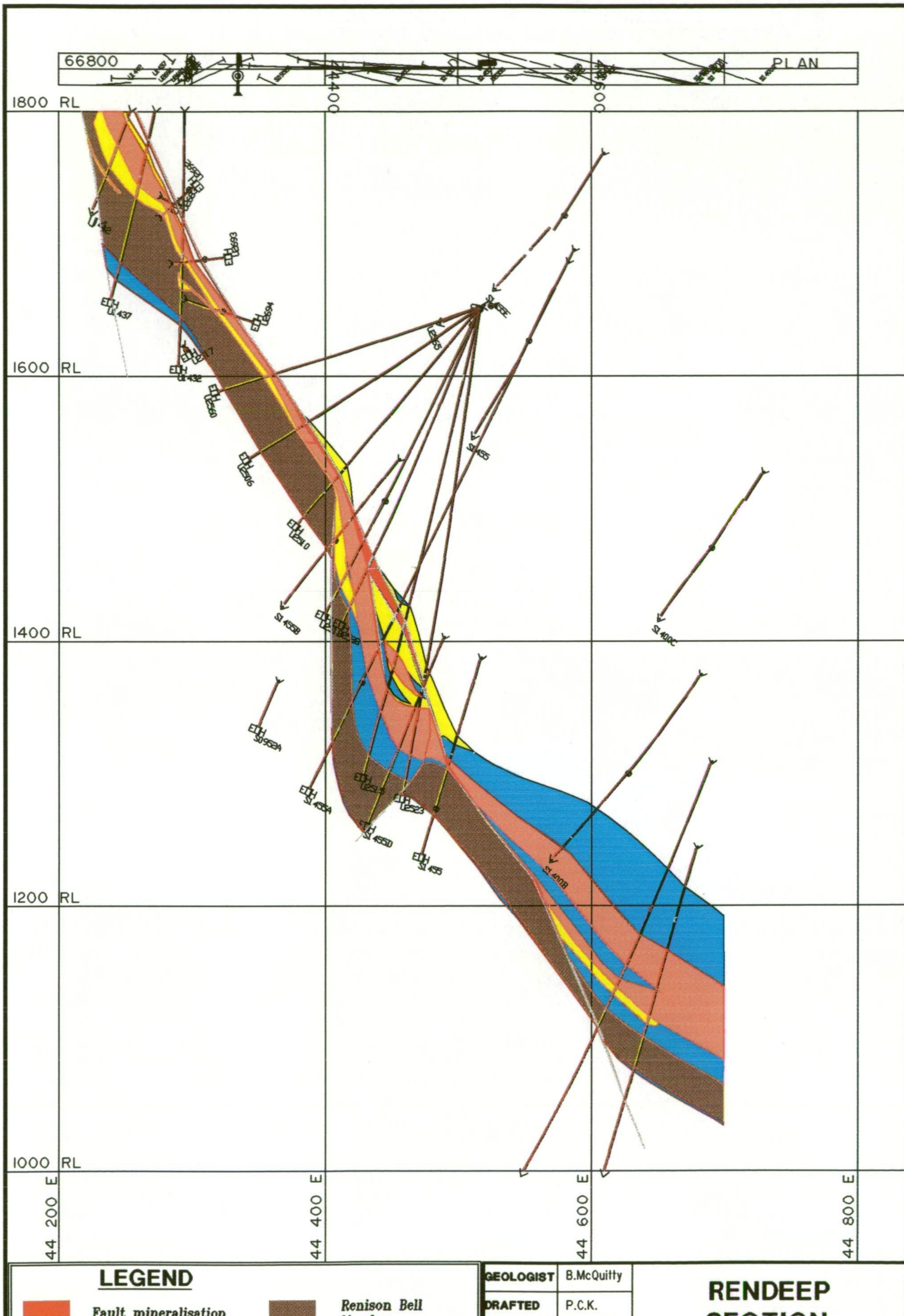

LEGEND

- Fault mineralisation
- Stratabound mineralisation
- Dolomite
- Renison Bell Member
- Dreadnought Hill Member
- Redrock Member

GEOLOGIST	B.McQuitty
DRAFTED	P.C.K.
DATE	08/01/95
CHECKED	

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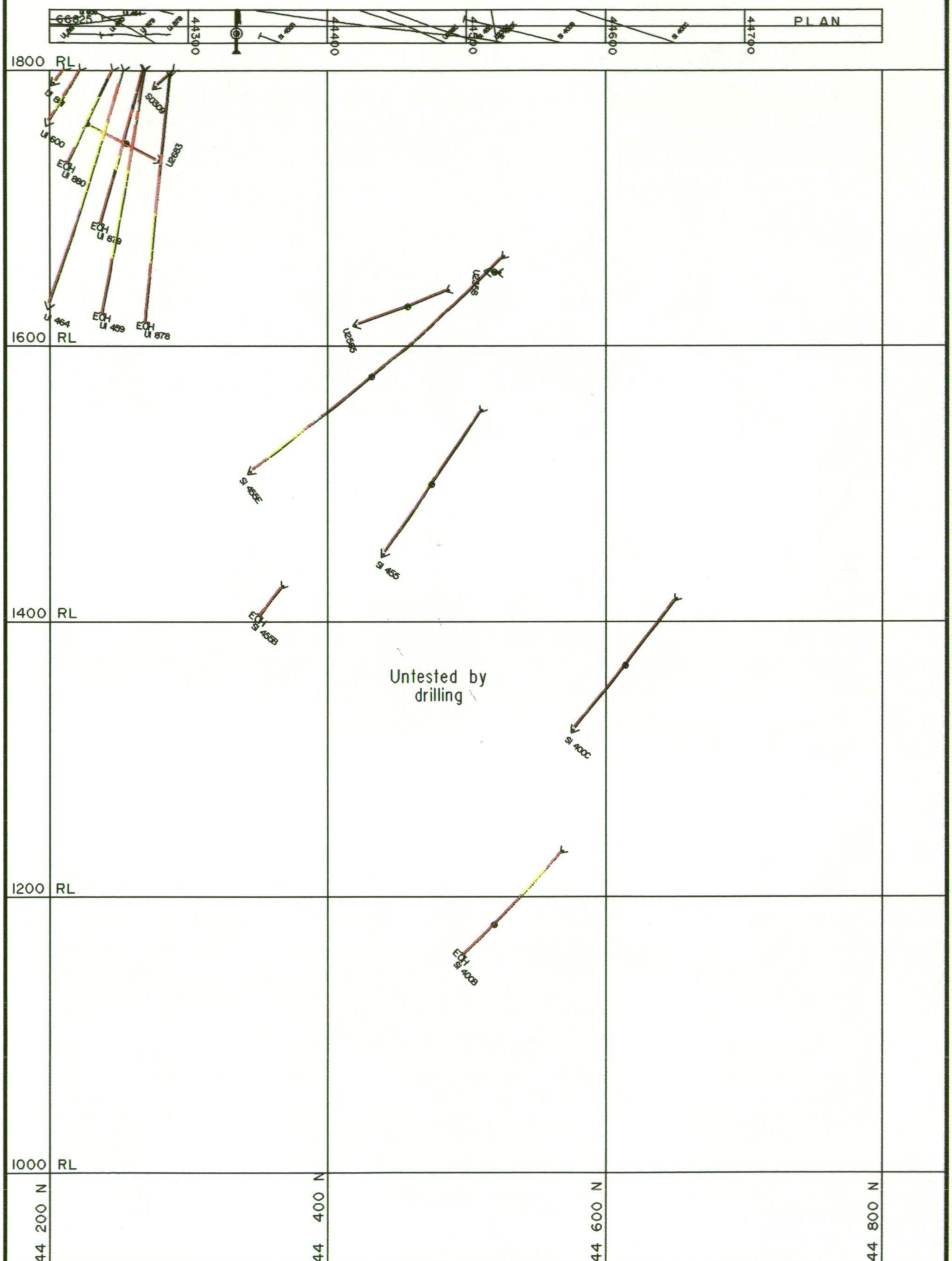

LEGEND

- Fault mineralisation
- Stratabound mineralisation
- Dolomite
- Renison Bell Member
- Dreadnought Hill Member
- Redrock Member

GEOLOGIST	B.McQuitty
DRAFTED	PCK
DATE	09/01/95
CHECKED	
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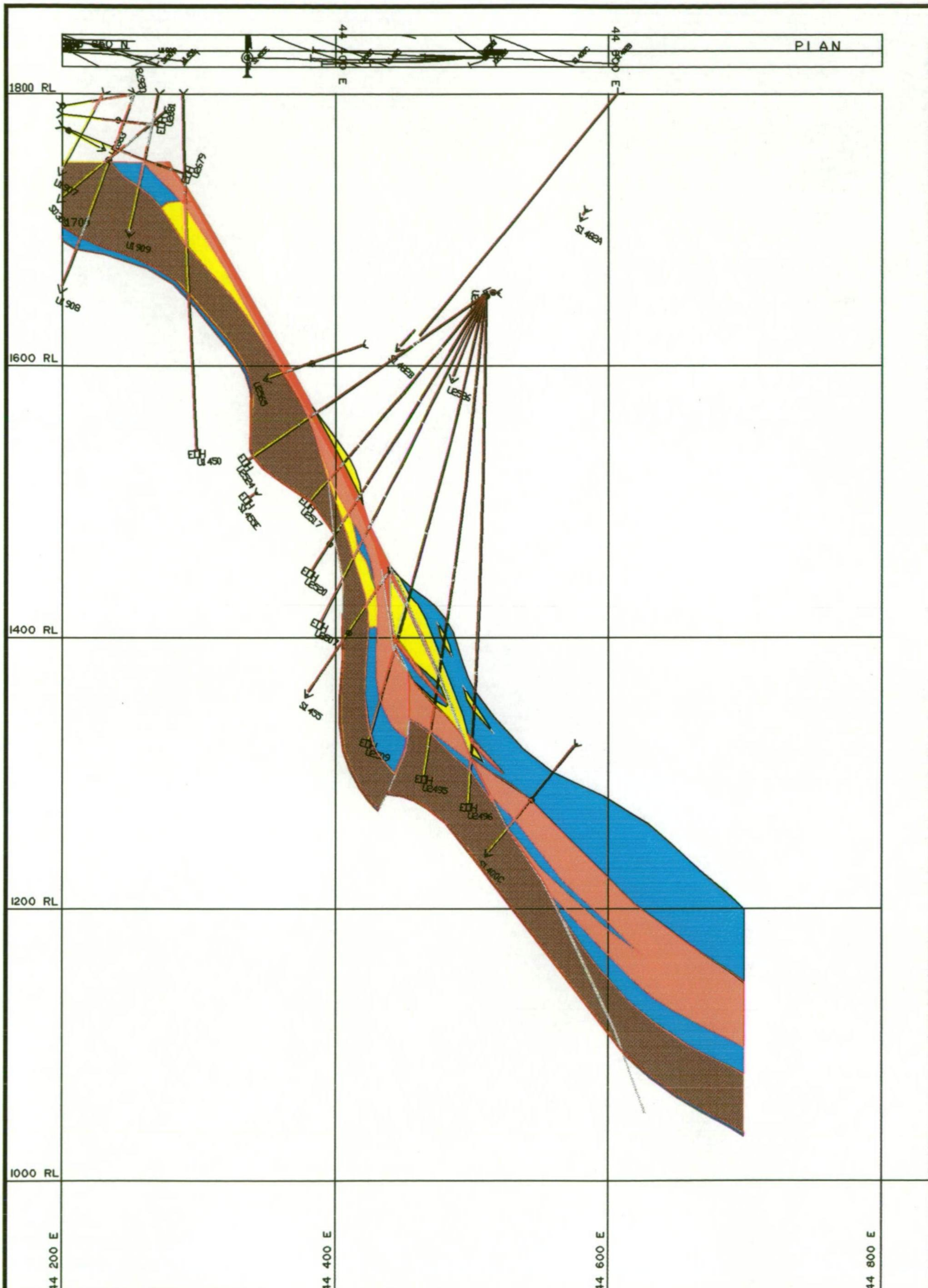
RENDEEP SECTION 66 825 N



GEOLOGIST	B.McQuitty
DRAFTED	S.F.M.
DATE	10/01/95
CHECKED	

RENDEEP SECTION 66 850 N

SCALE 1:4000

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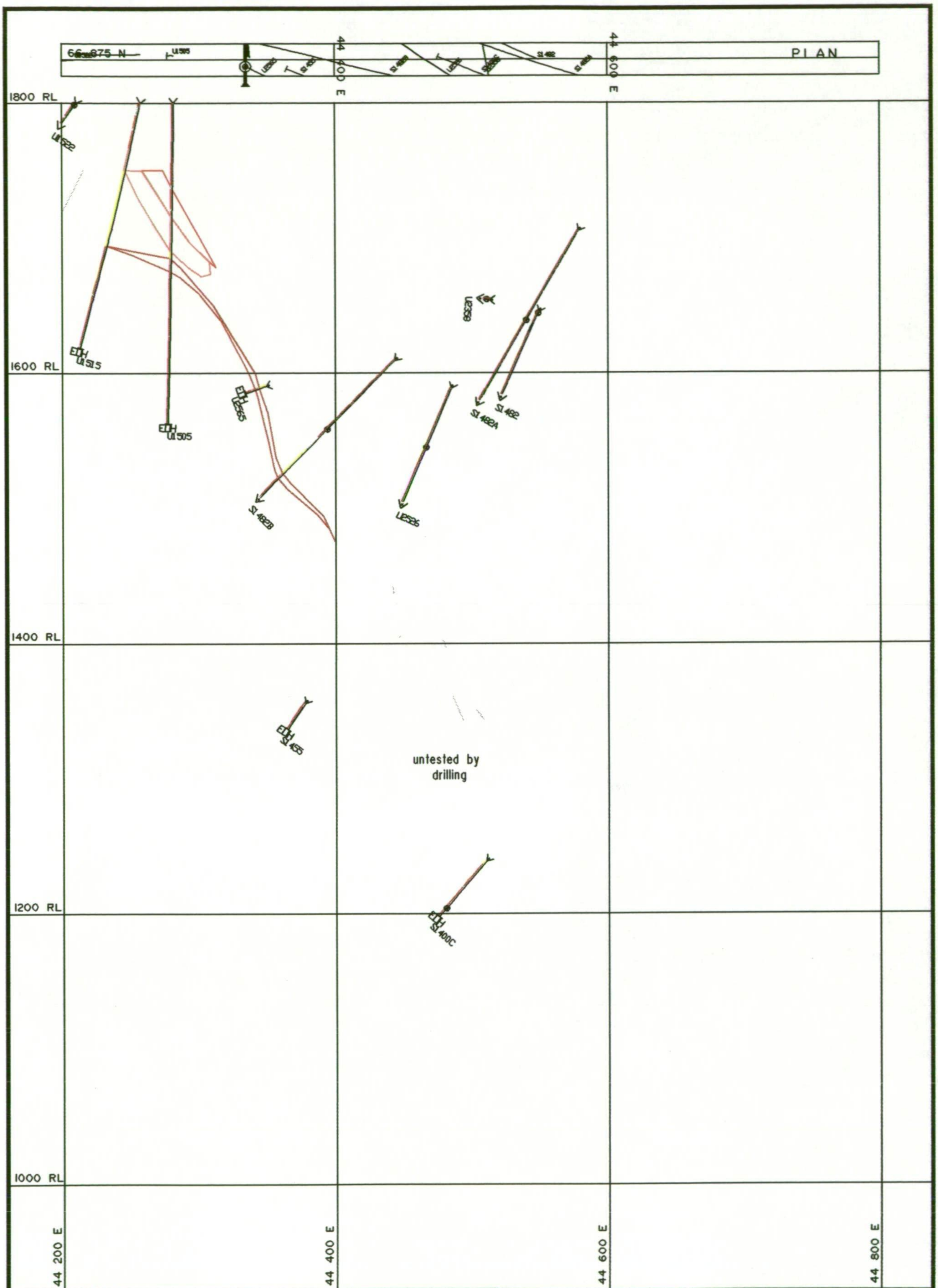

LEGEND

Fault mineralisation	Renison Bell Member
Stratabound mineralisation	Dreadnought Hill Member
Dolomite	Redrock Member

GEOLOGIST	B.McQuitty	RENDEEP SECTION 66 875 N
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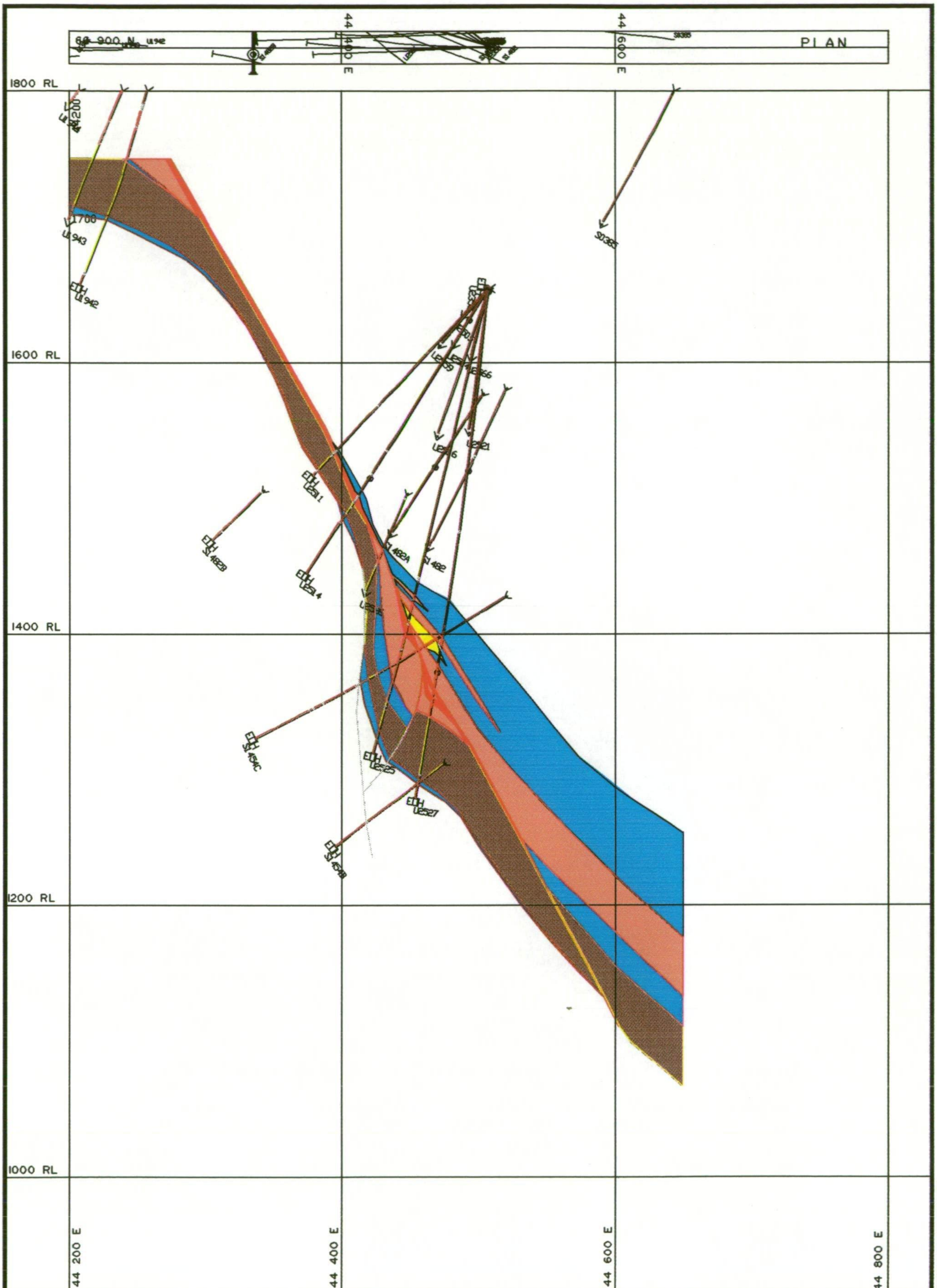
DATE	11/01/95	
CHECKED		

SCALE 1:4000



LEGEND

- Fault mineralisation
- Stratabound mineralisation
- Dolomite
- Renison Bell Member
- Dreadnought Hill Member
- Redrock Member

GEOLOGIST	B.McQuitty
DRAFTED	S.F.M.
DATE	11/01/95
CHECKED	

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RENDEEP SECTION 66 900 N

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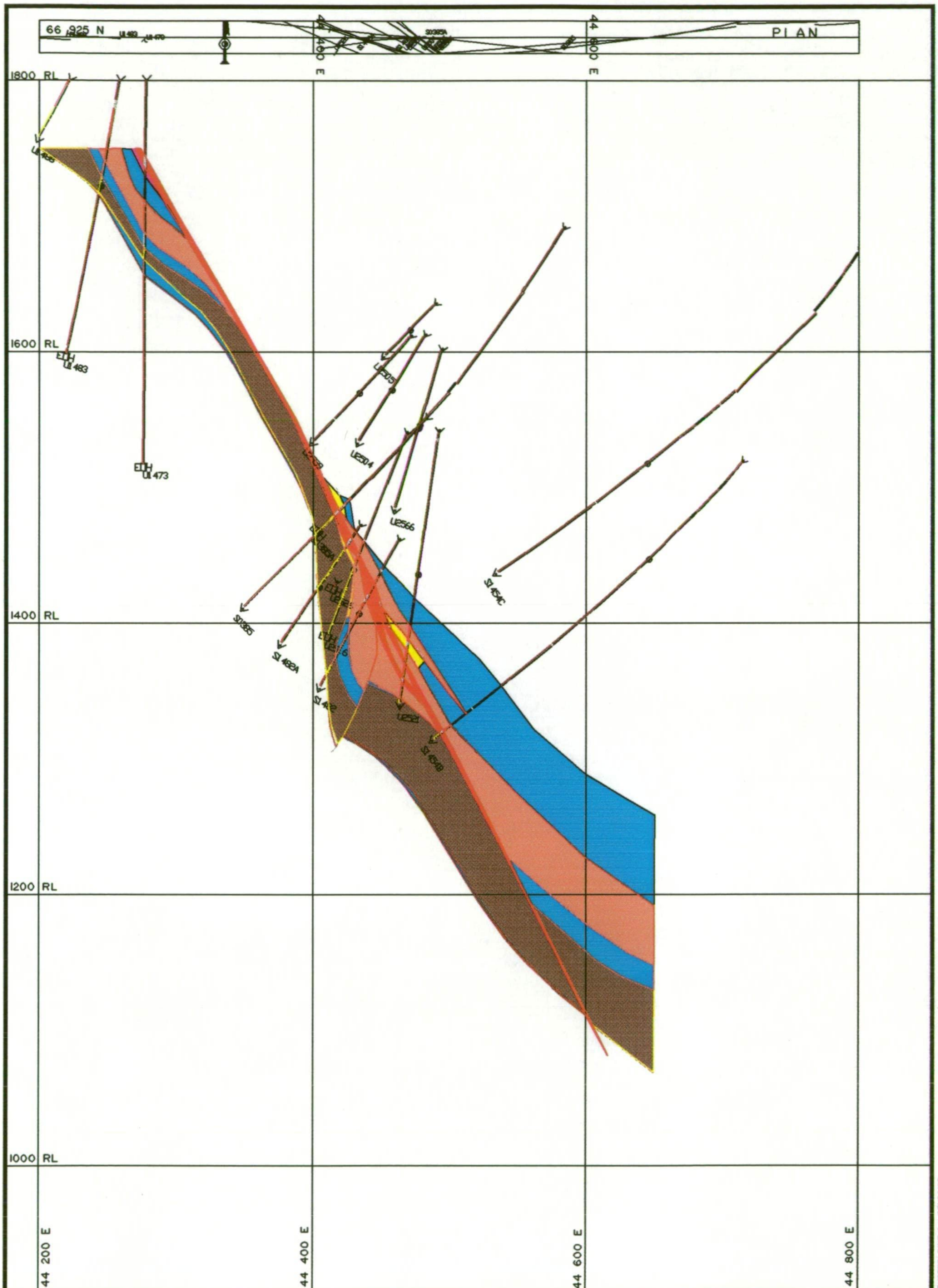

LEGEND

Fault mineralisation	Renison Bell Member
Stratabound mineralisation	Dreadnought Hill Member
Dolomite	Redrock Member

GEOLOGIST	B.McQuitty
DRAFTED	S.F.M.
DATE	13/01/95
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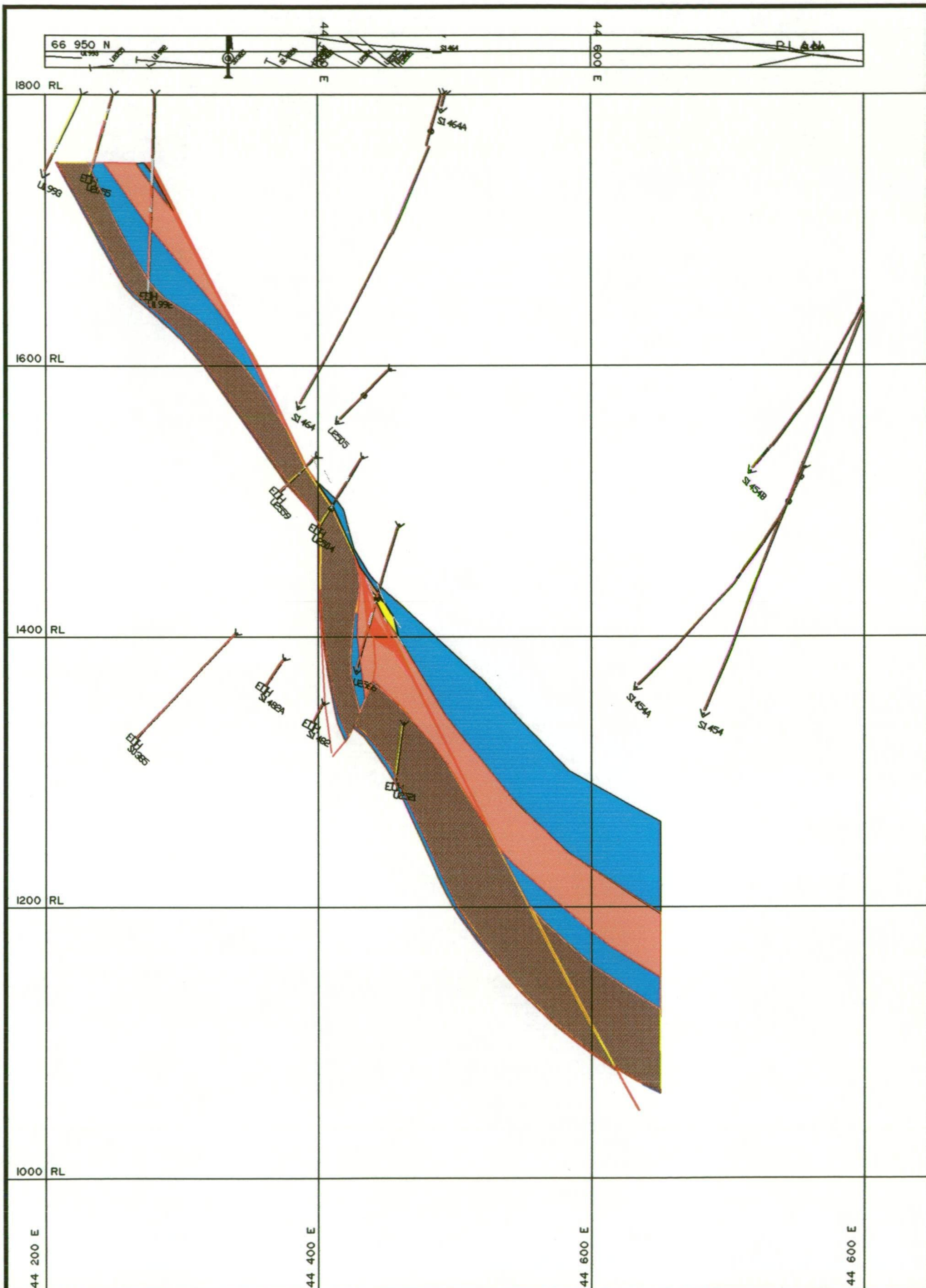

LEGEND

Fault mineralisation	Renison Bell Member
Stratabound mineralisation	Dreadnought Hill Member
Dolomite	Redrock Member

GEOLOGIST	B.McQuitty
DRAFTED	S.F.M.
DATE	13/01/95
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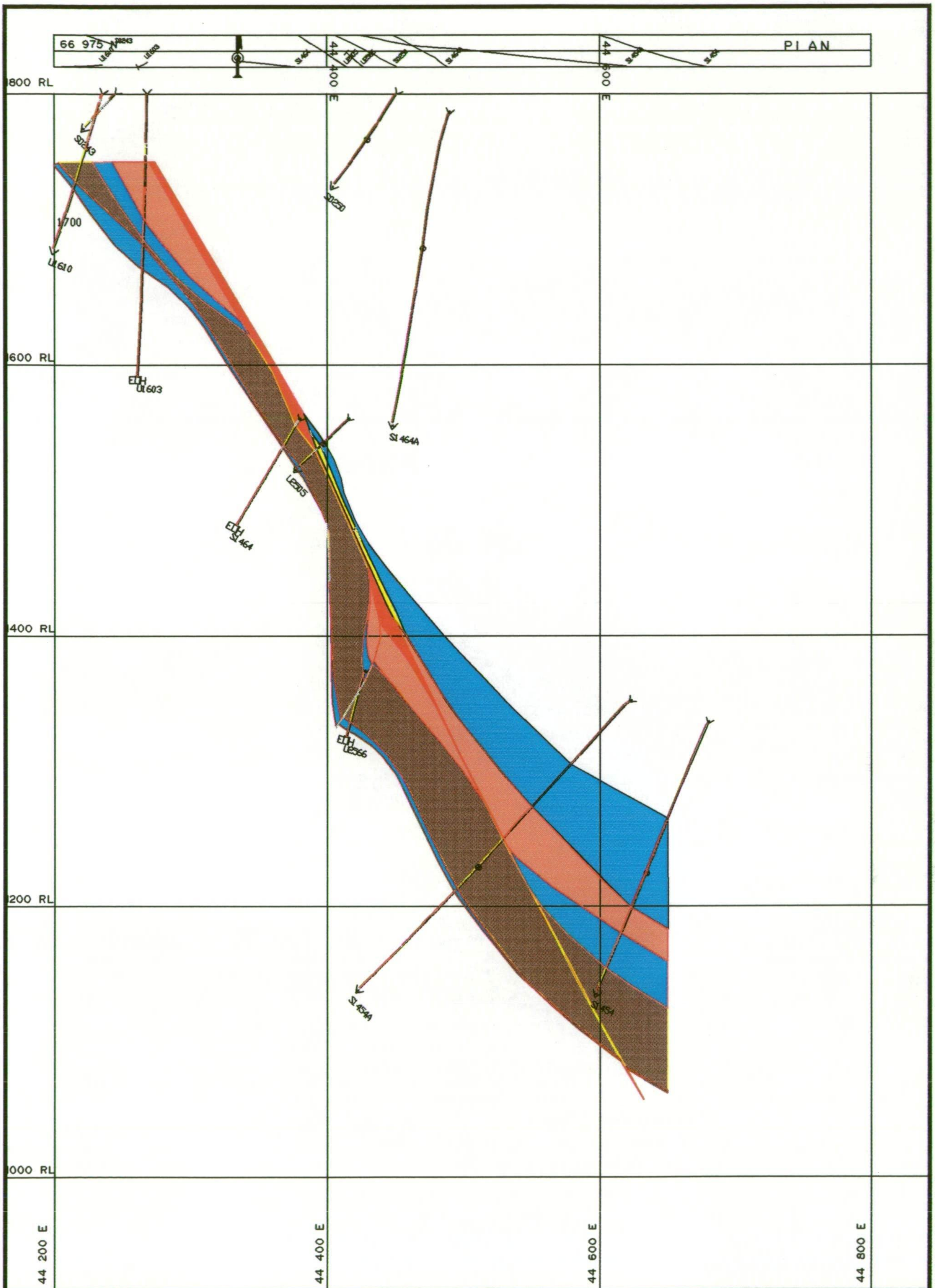

LEGEND

Fault mineralisation	Renison Bell Member
Stratabound mineralisation	Dreadnought Hill Member
Dolomite	Redrock Member

GEOLOGIST	B.McQuitty
DRAFTED	S.F.M.
DATE	13/01/95
CHECKED	

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RENDEEP SECTION 66 975 N

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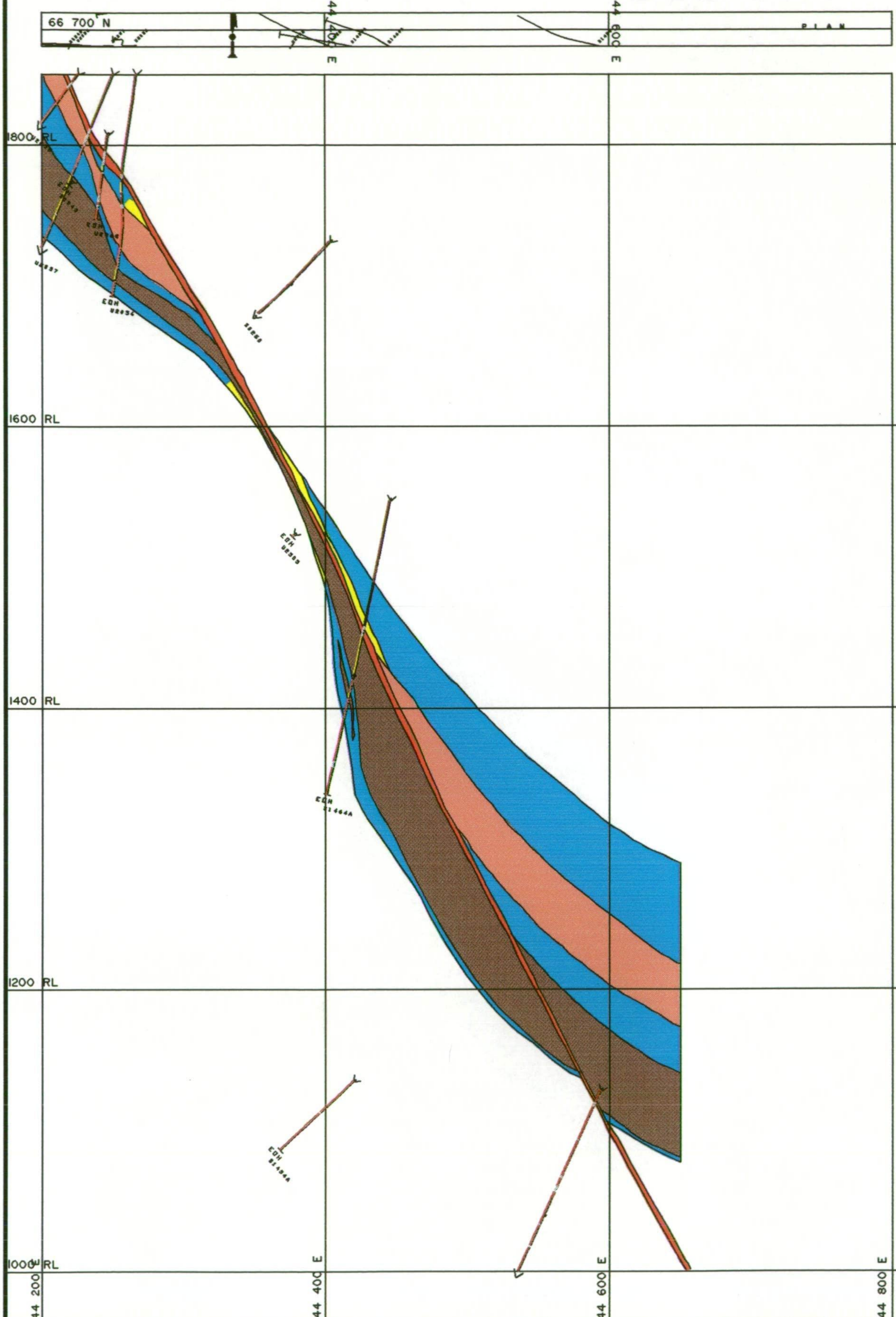

LEGEND

- Fault mineralisation
- Stratabound mineralisation
- Dolomite
- Renison Bell Member
- Dreadnought Hill Member
- Redrock Member

GEOLOGIST	B.McQuitty
DRAFTED	S.F.M.
DATE	13/01/95
CHECKED	

RENDEEP SECTION 67 000 N

SCALE 1:4000

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APPENDIX 2: OXYGEN AND SULPHUR ISOTOPE RESULTS

APPENDIX 2

OXYGEN AND SULPHUR ISOTOPE RESULTS

Drillhole	Depth (m)	Mineralogy	Paragenetic Stage (after Kitto, 1994)	$\delta^{18}O$(‰ vs SMOW)	$\delta^{34}S$ (‰ vs CTD)
S343	711.1	po-qt	Stage 2	+14.8	+6.6
S389	1077.2	po	Stage 2		+3.5
S440	400.8	qt-po	Stage 2 over Stage 1	+15.6	
S624	344.2	po-ac	Stage 2		+5.8
S814	978	qt-ap	Stage 1	+13.1	
S868	738	qt-ap-ct	Stage 1	+11.9	
S939	868.7	qt-ap	Stage 1	+13.7	
S1192	942	po-qt	Stage 2 over Stage 1	+14.4	+7.9
S1215	568.5	qt-ap-(po)	Stage 1	+13.7	+5.1
S1455	825	po-qt-ap-(fl)	Stage 2 over Stage 1	+14.4	+5.5
S1455C	873.2	qt-ct-ap	Stage 1	+15.0	
S1455C	927.2	po-qt	Stage 2		+12.5?
S1474	934	qt-ap-po	late stage py over Stage 1	+15.5	+5.9
S1475C	1042.9	qt-ap-ct	Stage 1	+14.3	+6.2
U1370	160.4	qt-ap-(po)	Stage 2 over Stage 1	+14.7	
U1879	133.2	qt-ap-(po)	Stage 2 over Stage 1	+14.0	+6.9
U2124	147.7	po-qt	Stage 2	+15.0	+6.3
U2194	115.4	qt-ap	Stage 1	+14.5	
U2342	99.5	po-(ap-qt)	Stage 2		+6.5
U2342	101	qt-(ap-po)	Stage 2?	+14.8	
U2384	34	ap-qt-(po-qt)	Stage 2 over Stage 1	+14.4	+6.9
U2484	175	ct-qt-ap-(po)	a little Stage 2 over Stage 1	+15.2	+6.4
U2505	175.4	po	Stage 2		+5.9
U2505	176.2	ct-qt-ap-(po-cp)	a little Stage 2 over Stage 1	+14.7	
U2521	286.7	qt-ap-(po)	Stage 2 over Stage 1	+15.2	+6.9
U2524	154.5	qt-ap-ct-(po-cp)	mainly Stage 1	+15.9	+6.9
U2702	234.5	ap-qt-ct-(cp-py)	a little Stage 2 over Stage 1	+14.5	
U2702	240.8	po-qt-(cb-qt)	Stage 3 over Stage 2		+5.2
U2706	263.1	po	Stage 2		+11.0?
U2708	235	ct-ap-qt-(po)	Stage 2 over Stage 1	+14.7	+6.6
U2726	369.5	qt-ap-po	Stage 2 over Stage 1	+13.4	+6.6
U2726	378	po-qt-(py-cb)	Stage 3 over Stage 2		+6.6
U2737	270.1	qt-ct	Stage 1	+15.2	
U2745	441.1	mt-po	Stage 2 over magnetite		+6.0

APPENDIX 3: FLUID INCLUSION STUDY RESULTS

APPENDIX 3

FLUID INCLUSION STUDY DATA

DDH	DEPTH	CHIP No.	HOST	TYPE*	Te (°C)	Tm (°C)	Th (°C)	NaCl eq. (wt%)	Comments
U2524	154.5	1	QUARTZ	s		-7.9	225		
S1474	934	1	"	s	-23	-4.2	186		
"	"	1	"	p	-21		365		50% vapour
"	"	2	"	p		-9.0	339.6	12.9	
"	"	2	"	s			184		
"	"	2	"	s	-27.0	-16.4	194		
U2484	175	1	"	s	-22.1	-3.9	154.5		
"	"	1	"	s			138.3		
"	"	1	"	s		+0.7	113		
U2484	174.7	1	"	s	-16	-9	196		
"	"	1	"	s			186		
"	"	2	"	ps			220		
"	"	3	"	ps?			205		
"	"	3	"	ps?			245		
U2708	234.8	1	"	ps	-25	-1.2	258		
"	"	1	"	ps			224		
"	"	1	"	ps			246		
"	"	2	"	ps	-17	-1.9	222		
"	"	2	"	ps			225		
U2726	269.6	1	"	s	-25	-11.4	160		
S1475C	1042.9	1	"	s	-25		217		
"	"	1	"	s			199		
"	"	3	"	ps	-26.7	-12.2	298		
"	"	3	"	p			>344.8		Decrepitated before homogenising
U2702	234.5	1	"	ps	-24.9	-9.0?	300		
"	"	1	"	ps			310		
"	"	1	"	ps			275		
"	"	1	"	p			337.9		
"	"	1	"	p			336		
"	"	1	"	p			326		
U2737	270.1	1	"	s			210		
"	"	1	"	s			200		
"	"	1	"	s			200		
S0868	731.8	1	"	ps			>280		Small, thick walled inclusion.

* s = secondary
* ps = pseudo-secondary
* p = primary

NOTE: All inclusions studied were the liquid + vapour type with vapour <50% of volume.